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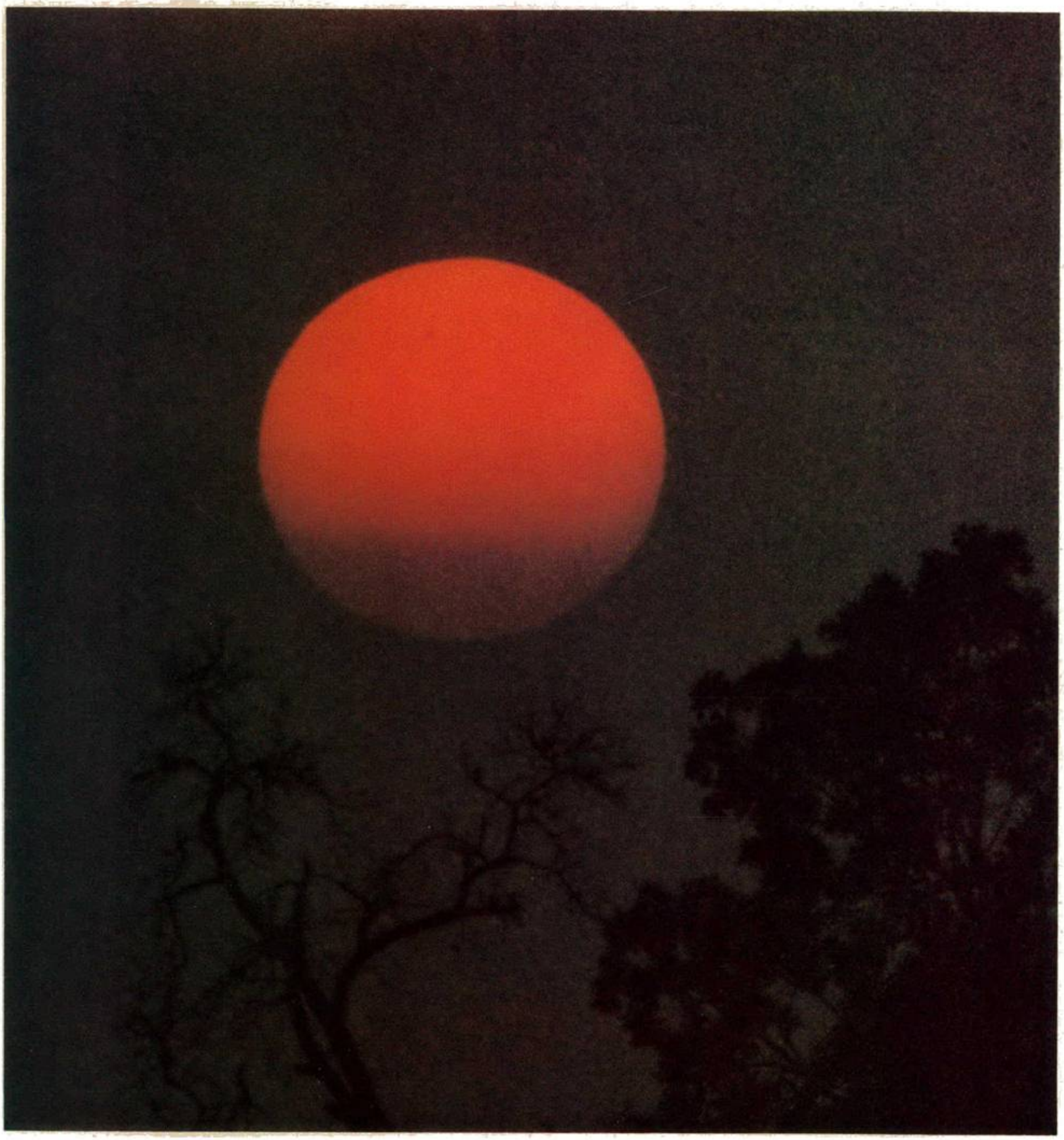

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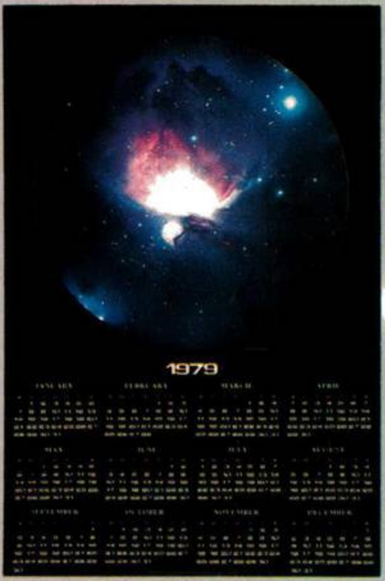

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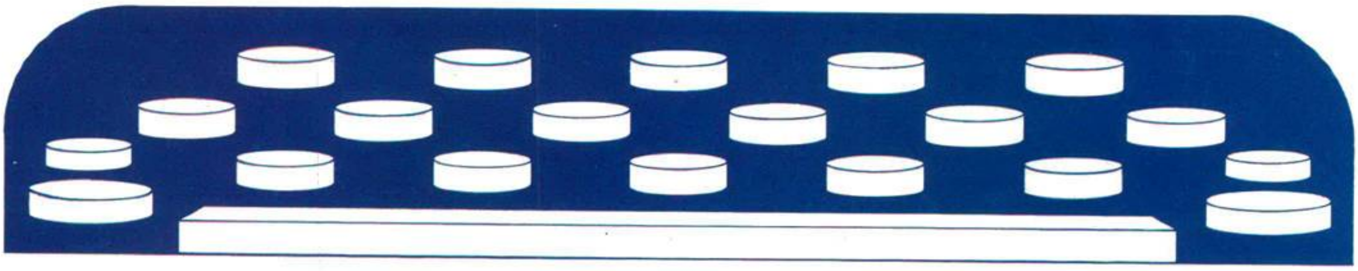

IN FOCUS

Sir / When Mercury and Venus reach inferior conjunction, do they ever pass across the face of the sun?
TOM SCANLAN
Villa Park, Ill.

Mr. Scanlan / Indeed, such events do happen, but only at rare intervals! The passage across the sun is called a transit, and was eagerly studied by astronomers during the past two centuries as a method for determining the size of the solar system. The remaining transits of Mercury in this century are: Nov. 13, 1986; Nov. 6, 1993, and Nov. 15, 1999. Transits of Venus occur much less often: The last ones were on Dec. 6, 1882 and Dec. 8, 1874, while the next two will be on June 7, 2004 and June 5, 2012!

Sir / In your September 1978 issue, page 14, a photograph of VV172 appears. What does VV mean?
JAMES P. CALK
Wolf Point, Mont.

Mr. Calk / VV172 is the designation of the object in the **Atlas and Catalogue of Interacting Galaxies** *compiled by Soviet astrophysicist Boris A. Vorontsov-Velyaminov, and published as a series by the Shternberg State Astronomical Institute, Moscow, starting in 1959.*

Sir / That's really quite a nice photograph of the "one day past first quarter" moon on page 32 of your October 1978 issue, but if people are to learn the value of knowing the phases of the moon for telling time, etc., will the orientation in your photograph help? After all — it's upside down! Oh, you'll say, but astronomers follow in the best traditions! Traditions should be broken when the majority involved benefit from a change which brings proper perspective. Otherwise, holding to tradition is esoteric and somewhat dehumanizing. Why sure, the pictures were taken through a telescope, but what else does the lay reader learn from that picture that isn't esoteric?
CHARLES PEIRCE
Crosby, N.D.

Mr. Peirce / We're really not trying to confuse anybody. The picture of the moon was run south-at-top because that is how it looks in most telescopes. We do break tradition regularly; many of our deep sky photographs are run north-at-top because that's the way most people are familiar with those fields. For example, the Lagoon and Trifid photograph (December 1978, page 14) is a sufficiently wide angle shot that it's familiar to photographers and binoculars users in that orientation. The Orion nebula looks best with south-at-top as seen in a telescope. We try to decide each case on its own merits and run the best presentation.

Sir / Could an entire galaxy become a black hole which might be called a "black galaxy"? For example, if more and more matter is piled up in our galaxy but its size is still the same, could it one day become a black hole by squeezing itself out of existence in the process of curving space around it so severely? If this can be true, is it possible to say that there is a black galaxy in the center of each supercluster of galaxies? We have recently detected x-ray emissions from these superclusters. Could these x-rays result from the falling matter of the galaxies into this black galaxy?
VU ANH QUANG
Houston, Tex.

Mr. Quang / According to theory, black holes can indeed come in any size whatsoever, from microscopic ones the size of nuclear particles to galactic and even greater volumes! But rather than a "black galaxy" as you suggest, many superclusters seem to have a supergiant elliptical galaxy at their centers. Some theorists, however, have suggested that galaxies coalesce in the first place around giant black holes. If this is so, the huge elliptical galaxies at the centers of large clusters may have supergiant black holes in them. Interestingly enough, though, as the mass of a black hole increases, the volume enclosed by its event horizon increases even faster so that the average density (mass/volume) of black holes decreases with their size. It turns out that the total mass of the universe might just be high enough to make the entire universe into a black hole — existing inescapably within the confines of a cosmic event horizon! We should emphasize, however, that it is not yet proven that black holes actually do exist apart from theory, though evidence is mounting.

Sir / While it is not recommended that a prospective purchaser of binoculars frequent the local discount houses or department stores, glasses of excellent quality are indeed available at moderate and low cost from quite a large number of sources. Photographic suppliers as **Popular Photography** and mail order houses such as Danleys (N.Y.) or United (Chicago) — to name but a few — offer a wide selection of these instruments with a complete range of prices.

While binoculars made by Zeiss, Leitz, etc. are certainly the ultimate in quality, it would be a serious mistake for the observer contemplating a purchase with a budget of $50 to $100 to refrain from doing so on the premise that the top quality glass in the $300 to $700 price range is necessary for astronomical observation. To do so would eliminate that extra dimension added to any observational program by these wide field instruments.

Binoculars of 10x or less, if *carefully* selected and tested, will match up with the top priced brands very favorably in practically every detail. I have verified this fact on many occasions with side by side tests comparing tripod mounted binoculars of numerous manufacturers.

A carefully selected binocular of moderate cost can match it's more expensive counterpart the important areas of resolution, light grasp and image definition. Only in the curvature of field is the expensive glass more consistently superior to a small degree.

Dr. Henry Paul in his **Binoculars and All Purpose Telescopes** further substantiated this fact when in discussing the cost of binoculars, he stated: "Actually excellent binoculars can be obtained for half, and serviceable glasses for about a fourth of maximum price."

As an example of the above, I have a 10 x 65 binocular that cost $39 (some years ago), which greatly exceeds in every category a Carl Zeiss (Jena) 7 x 50, and a Navy 7 x 50 Bausch & Lomb in simultaneous tests with the binoculars being tripod mounted.

Conversely, when the magnification reaches the 15x range, and in particular when considering the 20 x 80 binoculars easily obtainable from many sources today, collimation problems and many other deficiencies become immediately obvious in virtually all but the best glasses. With such binoculars, prime quality is a necessity, and according to the tests I have made, few glasses in this class provide a truly acceptable image for astronomical purposes.
ROBERT B. ARIAIL
Columbia, S.C.

ASTRONOMY

The World's Most Beautiful Astronomy Magazine

Vol. 7, No. 2 February 1979

Established August 1973 by Stephen A. Walther

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COVER

The setting sun sometimes displays spots that are visible to the unaided eye. Records of just such spots, collected over millennia of observation by ancient Chinese astronomers, now suggest to modern astrophysicists that the sunspot cycle has been inconstant over the last several thousand years. This month's Stellar Frontiers tells the story. We also know that over a time span of billions of years, the sun must vary as it uses its fuel and evolves. Our feature deals with the evolution of the sun — indeed, with the life history of all stars — from cosmic gas to black hole, pulsar or white dwarf. And this month's departments tell you how to improve your astronomical slides and provide a basic course in eyepieces and how to choose them. There is a selection of excellent black and white pictures from our readers and, of course, book reviews, observing information, and the latest Astro-News. Photograph by Eddie J. Garrett.

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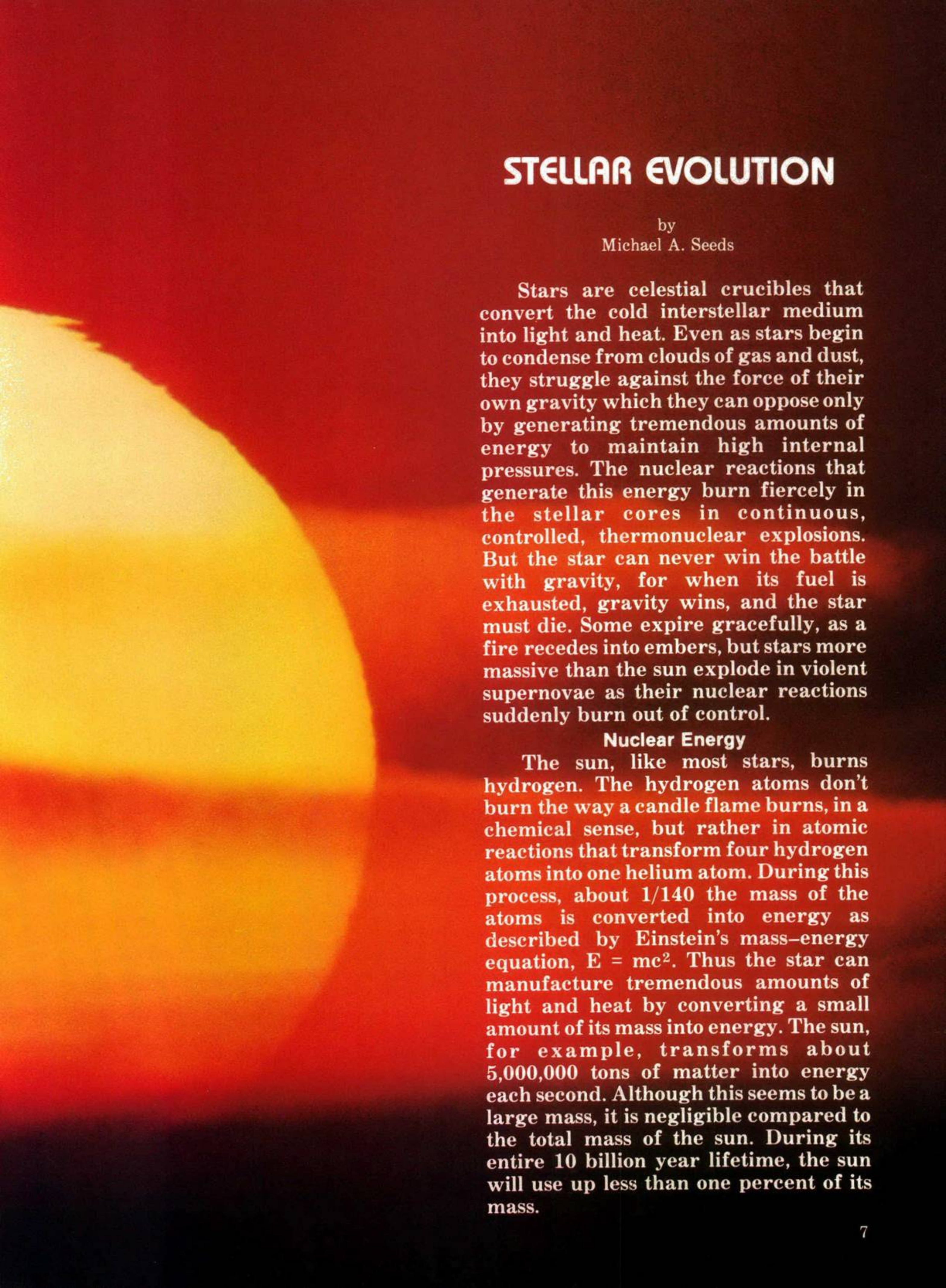
Our sun, like every other star, continuously emits energy, and therefore must eventually change. Every year, deep in its interior, it converts some 17 million trillion tons of hydrogen into 16.9 million trillion tons of helium — and the mass difference is converted into energy. Not only will the sun eventually use up its supply of hydrogen, but it's also altering its own composition — becoming helium rich — as it burns. After some 10 billion years of normalcy, the sun will swell into a red giant, incinerating Earth in the process. Photograph by James Boyd.



STELLAR EVOLUTION

by
Michael A. Seeds

Stars are celestial crucibles that convert the cold interstellar medium into light and heat. Even as stars begin to condense from clouds of gas and dust, they struggle against the force of their own gravity which they can oppose only by generating tremendous amounts of energy to maintain high internal pressures. The nuclear reactions that generate this energy burn fiercely in the stellar cores in continuous, controlled, thermonuclear explosions. But the star can never win the battle with gravity, for when its fuel is exhausted, gravity wins, and the star must die. Some expire gracefully, as a fire recedes into embers, but stars more massive than the sun explode in violent supernovae as their nuclear reactions suddenly burn out of control.

Nuclear Energy

The sun, like most stars, burns hydrogen. The hydrogen atoms don't burn the way a candle flame burns, in a chemical sense, but rather in atomic reactions that transform four hydrogen atoms into one helium atom. During this process, about 1/140 the mass of the atoms is converted into energy as described by Einstein's mass–energy equation, $E = mc^2$. Thus the star can manufacture tremendous amounts of light and heat by converting a small amount of its mass into energy. The sun, for example, transforms about 5,000,000 tons of matter into energy each second. Although this seems to be a large mass, it is negligible compared to the total mass of the sun. During its entire 10 billion year lifetime, the sun will use up less than one percent of its mass.

Great clouds of glowing hydrogen gas and opaque dust surround a cluster of hot, young, massive stars. Ultraviolet light radiated by these stars excites the gas, backlighting denser dark clouds and wisps of material condensing slowly into stars. This region, called the Rosette nebula, is a site of recent — and continuing — star formation. Some 50 light-years across, there is material on hand to form over 10,000 stars. Photograph by Evered Kreimer.

The nuclear reactions required to make so much energy can occur only near the center of the star. Only there is the gas hot enough and dense enough to react. The nuclei of hydrogen atoms have positive charges that repel each other, so it is unlikely that they will get close enough to react unless they collide violently. Such collisions occur only in a hot gas where atoms move at high velocities. But a single reaction generates very little energy, hardly enough to raise a house fly 1/1,000 inch! Only in the dense stellar core — where collisions are frequent — can there be enough reactions to balance the immense energy budget of a star.

The nuclear reactions that transform hydrogen into helium can occur in two ways. One process, the *proton-proton chain*, is a simple sequence of three nuclear reactions that work well at temperatures below 16,000,000 degrees Kelvin. Another process, called the *CNO cycle*, is more complex, involving six different reactions that use carbon, nitrogen and oxygen as stepping stones to helium. Although the CNO cycle also combines four hydrogen atoms to make one helium atom plus energy, it is much more efficient at temperatures above 16,000,000 degrees Kelvin. Both processes operate in the core of the sun (where the temperature is 15,000,000 degrees Kelvin), but the proton-proton chain produces 90 percent of the energy. The CNO cycle produces the rest.

Other nuclear reactions are possible, but they require much higher temperatures. For example, three helium atoms can combine to form a carbon atom plus energy, but the gas must have a temperature of 100,000,000 degrees Kelvin or higher. This helium burning becomes important in giant stars, as do reactions that burn carbon and other heavy elements at temperatures of 600,000,000 degrees Kelvin and higher.

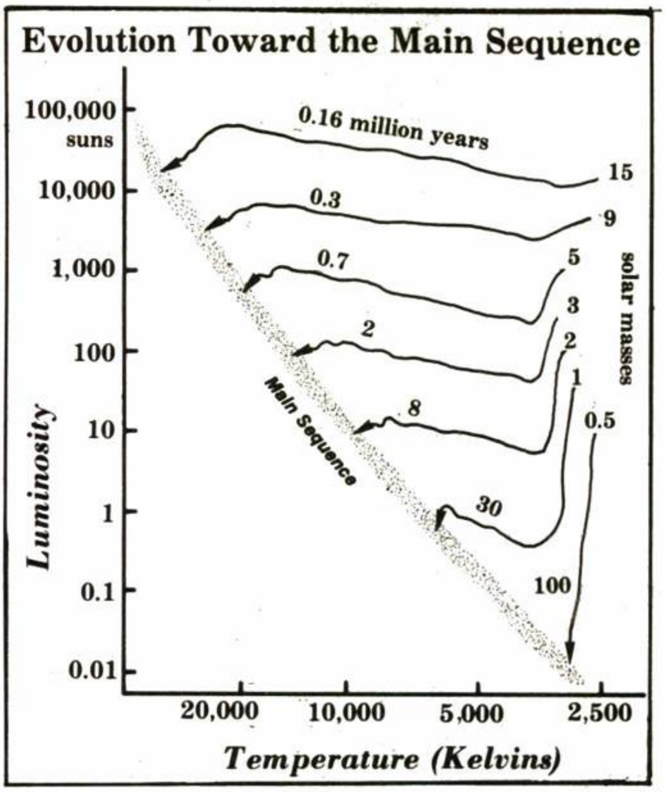
Gravitational Energy

Since nuclear fusion can occur only at very high temperatures and densities, how do stars get started? It seems difficult — at first glance — for a star to get hot if it forms from the cold gas and dust of the interstellar medium. Fortunately, stars can draw on gravity to heat up to the temperature at which fusion begins. To understand how this gravitational energy source works, let's follow the condensation of a cloud of cold interstellar gas into a cluster of stars.

The gas between the stars, called the *interstellar medium,* is mostly hydrogen (80 percent) and helium (20 percent), with traces of heavier atoms and dust. This interstellar medium is spread through the galaxy as a very low density, high temperature sea in which drift cooler, denser clouds of similar composition, like chunks of ice floating in water. If one of these denser clouds happened to become gravitationally unstable and fell in on itself, it could form a large cluster of new stars. The clouds, however, are not dense enough to begin contraction on their own — some outside force must trigger the collapse. Computer models show that when a cloud collides with a shock wave (the astrophysical equivalent of a sonic boom), or with some of the dense regions of the galactic spiral arm, the cloud breaks up. A few of the fragments get strongly compressed, triggering their collapse into a cluster of stars.

A cloud fragment collapsing into a star is heated by its own gravity. As the material falls together, the gas atoms pick up speed, falling faster and faster toward the center. By the time the gas becomes dense enough for the atoms to collide frequently, they are traveling at high velocities. Since temperature is just a way of measuring the average velocity of the atoms within a body, the contracting gas cloud becomes hot. The cloud can continue to contract and heat up until it is hot enough to ignite hydrogen fusion reactions.

We call this a *gravitational energy source* because the collapsing cloud converts its gravitational energy into thermal energy. This is an important principle in the study of stars, for whenever a star contracts, it gains thermal energy, and when it expands, it loses thermal energy.



Evolution Toward the Main Sequence

Massive stars evolve quickly and move from the red giant region to the main sequence in less than a million years, while lower main sequence stars take many millions of years to begin their main sequence lives.

The Formation of Stars

To follow the evolution of a star from its origin as a contracting cloud of gas, we can plot it in a temperature-luminosity (T-L) diagram such as the one shown on this page . In this diagram the total luminosity appears on the vertical scale, and the surface temperature on the horizontal scale. Ninety percent of all stars lie in a band called the main sequence, running from hot, bright stars to cool, faint stars. A cloud of gas beginning the contraction that leads to star formation lies far to the lower right in the region of very cool, very faint objects.

To be stable — to remain the same size, that is — a star must be in gravity-pressure balance. Throughout the star, the inward force of gravity must be balanced by the outward pressure of the gas. A collapsing cloud of gas, however, is far from stable because the internal pressure is very low. Consequently, gravity wins and the cloud contracts rapidly. During this free fall phase, temperature rises, dust vaporizes, and pressure begins to grow as the atoms fall closer to the center of the cloud. Eventually the pressure becomes great enough to halt the rapid contraction — and a *protostar* is born.

A protostar is not yet a star because it has not become hot enough to burn nuclear fuels. Nevertheless, it is a starlike object a few thousand times larger than the sun with a surface temperature of about 4,000 degrees Kelvin. If we could see such an object it would be very luminous and red, appearing in the red giant region of the T-L diagram.

Unfortunately, protostars are not detectable at visual wavelengths. They are completely hidden deep within the cloud from which they formed. The dust in the cloud absorbs the light from the protostar and reradiates it as infrared radiation. Observations with infrared telescopes reveal a number of objects that may be protostars forming within their dust cocoons. For example, an infrared source called the *Kleinmann-Low* object (after its discoverers), located behind the Orion nebula, is apparently a contracting cloud in the first stages of star formation. Since the Orion region contains many young stars, the discovery of infrared objects there gives astronomers confidence in this theory of protostar formation.

Models of Stars

The "time machine" that makes possible the study of stellar evolution is the modern computer. By building mathematical models with a computer, astronomers can study internal stellar structure, and by projecting the future behavior of the models, it's possible to follow the evolution of stars over billions of years.

Stars are great spheres of hot gas, held together by their own gravity. Their internal structure depends on four physical principles or "laws": conservation of mass, conservation of energy, gravity-pressure equilibrium, and transport of energy. While the first two principles are familiar, the last two deserve some explanation.

The principle of gravity-pressure equilibrium says that at every layer in the star, the weight of the gas pressing down must be balanced by the internal pressure pushing up. If this were not true, the star would expand, contract, or perhaps even explode. Since we are interested in stable stars, we must be sure that every layer is in equilibrium.

The principle of energy transport says that energy must flow from hot regions to cool regions according to certain rules. If the gas is hot it will be partially transparent and the energy will flow as radiation (light, x-rays, gamma rays, etc.). But if the gas is cooler, it will be less transparent and the radiation will not flow through easily. Energy will back up like flood waters behind a dam, and the gas will begin to churn in a boiling motion called convection. Hot gas will rise upward and cool gas will sink, carrying energy as heat in the gas rather than as radiation. Since energy can move through the star as radiation or as convection, the principle of transport of energy must include both possibilities.

To build a model of a star, a theoretical astronomer first thinks of the star as made of concentric layers — like the layers of an onion. For each layer, we can write the four principles described above as differential equations. Since a model star often consists of 100 layers, we will have a list of at least 400 equations that must all be solved together. The unknowns in these equations will be the temperature and pressure of the gas in each layer, the mass inside each layer, and the energy flowing through each layer.

Solving such a swarm of equations would be nearly impossible if computers did not do the arithmetic. If we program the computer correctly and give it the proper data, it can solve the equations in a few seconds, giving us a stellar model in the form of a table of numbers that describes conditions throughout all layers within the star.

The model shown on page 11 describes the internal structure of the sun. As you run your eye from the top of the table to the bottom, you are descending from the surface of the sun toward its center. The temperatures increases rapidly as you move downward. At the center, the temperature reaches a maximum of 15,000,000 degrees Kelvin. The high temperature makes the gas transparent, so the energy flows away from the center as radiation. In the outer layers, however, the gas is cooler and therefore less transparent, so the energy flowing outward forces the gas to become convective. This model of the sun, like all stellar models, gives us an otherwise impossible opportunity to study the invisible layers inside a star.

Although the protostar is no longer in free fall contraction, it is not quite stable because it's not hot enough to begin fusion reactions. As it radiates energy from its surface it must contract and draw on its gravitaional energy to make up the loss. This thermal contraction slowly heats the protostar, taking millions of years to reach high enough temperatures to begin fusion. During this contraction the surrounding cocoon nebula clears as parts of it are absorbed while other parts are blown away by radiation from the protostar.

At first the protostar is entirely convective, meaning that energy flows outward as rising currents of hot gas and sinking currents of cool gas. As the interior temperature rises, the gas becomes more transparent, and the energy begins to flow outward as radiation. The churning convective motion then stops. The transition to a completely radiative protostar causes a rapid move toward the hot side of the T-L diagram as the radiation carries energy upward and makes the surface hotter.

How long a star takes to reach the main sequence depends on its mass. The more massive it is, the stronger its gravity and the faster it contracts. A star like the sun, for example, takes 30 million years to reach the main sequence, but a 15 solar mass star takes only 160,000 years.

As the star nears the main sequence, its core finally becomes hot enough to burn hydrogen. Gradually at first, and then more rapidly, internal temperature and pressure increase as the nuclear energy source turns on, until at last the pressure stops the contraction. The new star settles onto the main sequence where it will spend most of its life caught in a battle between gravity and pressure, a battle that always ends with the death of the star when its nuclear fuel runs out.

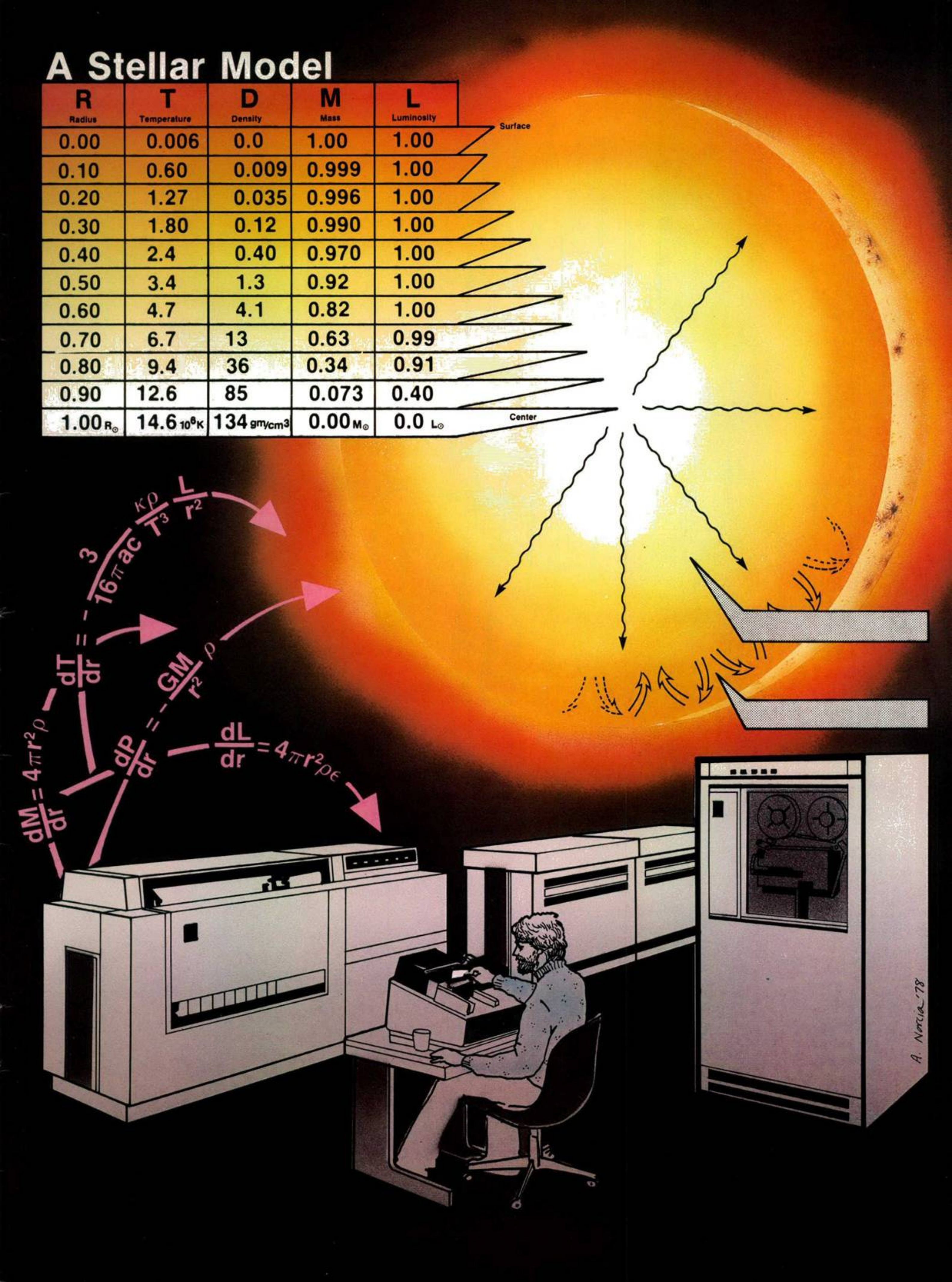
Main Sequence Stars

All main sequence stars burn hydrogen, but stars more massive than about 1.1 solar masses are hot enough to burn on the CNO cycle, while less massive stars (such as the sun) burn hydrogen via the proton-proton chain. This difference in energy generation produces a difference in internal structure, and divides main sequence stars into two types.

The CNO cycle is very sensitive to temperature: It produces much more energy at higher temperatures. Thus more massive stars generate most of their energy in a small central region where the temperature is highest. For example, a 10 solar mass star generates 50 percent of its energy in its central 2 percent of mass. This concentrated energy generation creates problems for the star. Even though the gas is hot and relatively transparent, energy can't flow away from the center fast enough. A "traffic jam" develops, and the energy backup forces the core of the star to churn in convection. Some of the overheated core gases rise, carrying energy away from the core.

A Stellar Model

R Radius	T Temperature	D Density	M Mass	L Luminosity	
0.00	0.006	0.0	1.00	1.00	Surface
0.10	0.60	0.009	0.999	1.00	
0.20	1.27	0.035	0.996	1.00	
0.30	1.80	0.12	0.990	1.00	
0.40	2.4	0.40	0.970	1.00	
0.50	3.4	1.3	0.92	1.00	
0.60	4.7	4.1	0.82	1.00	
0.70	6.7	13	0.63	0.99	
0.80	9.4	36	0.34	0.91	
0.90	12.6	85	0.073	0.40	
$1.00\,R_\odot$	$14.6\ 10^6$K	134 gm/cm³	$0.00\,M_\odot$	$0.0\ L_\odot$	Center

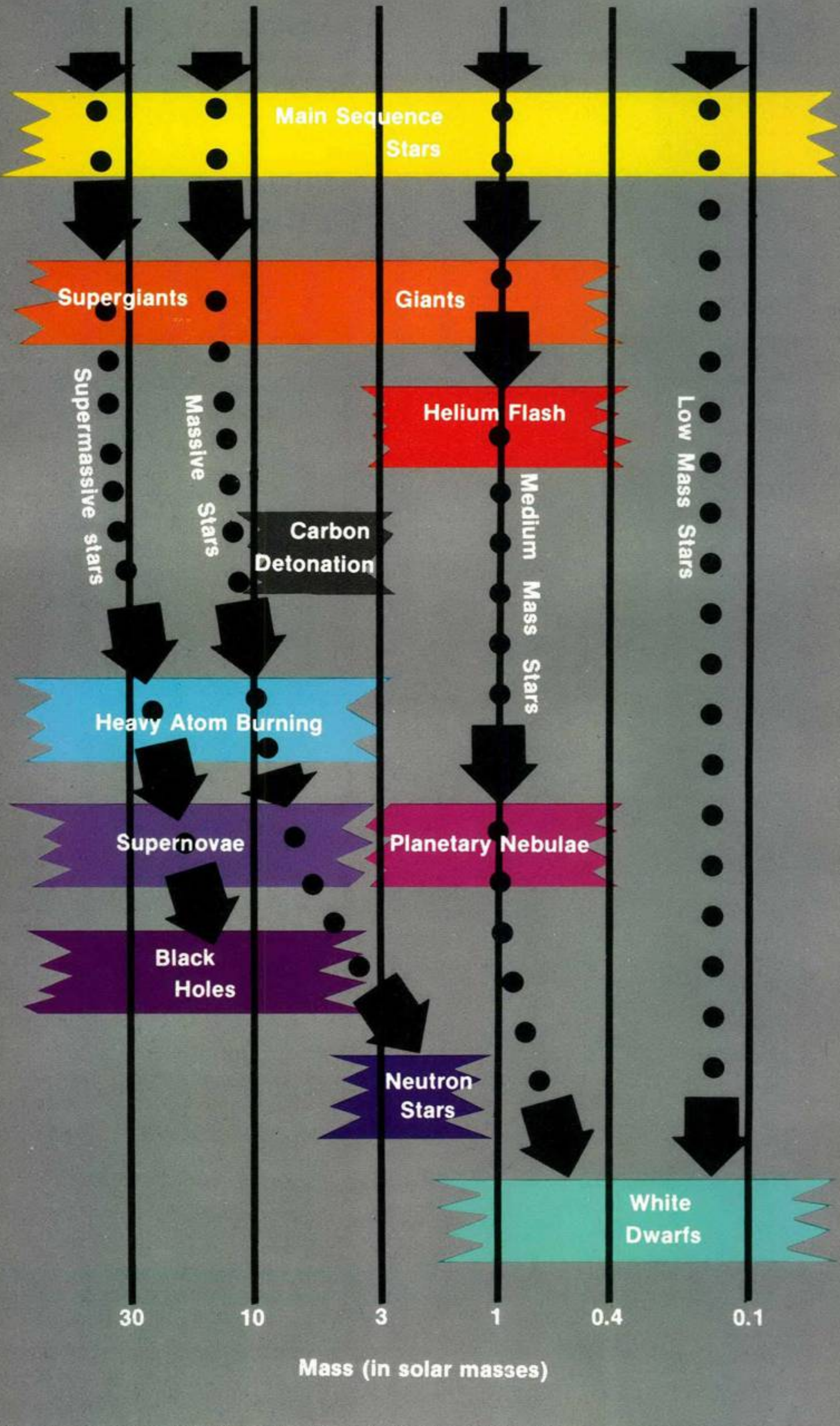


$$\frac{dM}{dr} = 4\pi r^2 \rho$$

$$\frac{dT}{dr} = -\frac{3}{16\pi ac}\frac{\kappa\rho}{T^3}\frac{L}{r^2}$$

$$\frac{dP}{dr} = -\frac{GM}{r^2}\rho$$

$$\frac{dL}{dr} = 4\pi r^2 \rho\epsilon$$


Main Sequence Stars
Supergiants
Giants
Supermassive stars
Massive Stars
Helium Flash
Low Mass Stars
Carbon Detonation
Medium Mass Stars
Heavy Atom Burning
Supernovae
Planetary Nebulae
Black Holes
Neutron Stars
White Dwarfs
30
10
3
1
0.4
0.1
Mass (in solar masses)

The evolutionary stages of a star's life depend almost entirely on its initial mass. The lowest mass stars evolve directly to white dwarfs, while medium mass stars like the sun become giants and form planetary nebulae before becoming white dwarfs. Massive stars and supermassive stars may loose mass in various ways as they evolve through the giant or supergiant stage into neutron stars or black holes.

Once the energy gets away from the center, out of the jammed energy generating region, it can flow as radiation (light, ultraviolet, x-rays, etc.) through the hot gas to the star's surface. Thus massive stars have convective cores and radiative envelopes.

Less massive stars have radiative cores and convective envelopes. Their cores are radiative because they are cooler and burn on the proton–proton chain, which is less temperature sensitive. Consequently the energy generation is not concentrated at the center but is distributed throughout the central 15 percent of the mass of the star. No traffic jam develops and no convection occurs. The energy flows outward as radiation until it reaches the outermost layers that are too cool to permit its passage. There the energy backs up and convection occurs. In stars less than about 0.4 solar masses, the gas is so cool that convection carries energy all the way from its center to its surface.

Upper main sequence stars consume fuel faster because they have more weight to support, and only by generating a tremendous amount of energy do they balance their own gravity. Lower main sequence stars, having less weight to balance, burn fuel more slowly and live long main sequence lives. For example, the sun can remain on the main sequence for about 10 billion years, but a 25 solar mass star will run out of fuel in only 3 million years. Thus the *more* massive a star is, the *less* time it spends on the main sequence.

Giant Stars

When a star exhausts its hydrogen fuel, it can no longer generate energy to balance its weight and it must contract. Contraction converts gravitational energy into thermal energy and heats the core. Just outside the core, unburnt hydrogen reaches ignition temperature, and the star begins generating energy in a hydrogen burning shell surrounding the contracting core. The energy released by the hydrogen burning shell forces the envelope — the outer layers of the star — to expand and grow cooler, transforming the star into a cool giant.

If we could explore the inside of such a giant star, we would find a small, tremendously dense core of helium surrounded by a hydrogen burning shell. The envelope of the star would be less dense than air. If we could insulate ourselves from the heat, we could fly an airplane through most of a giant star. Only near the center, where densities are high, would we be in any danger.

As the helium core contracts it grows hotter. This sets the scene for a violent explosion in the core as the helium begins to burn. To see how this explosion occurs, let's first examine the "thermostat" that controls the nuclear reactions. In the sun, for instance, the pressure depends on the temperature and, if the nuclear reactions begin to produce too much energy, the temperature climbs and raises the pressure. The increased pressure forces a slight expansion which reduces the density and temperature and slows down the nuclear reactions. As long as the pressure in a star's core depends on the temperature, this pressure–temperature thermostat will keep the nuclear reactions under control.

However, the contracting helium core in a giant star can become so dense it cannot act like a normal gas. Gas in this condition is called a *degenerate gas*. In such material the pressure no longer depends on the temperature, and the pressure–temperature thermostat is turned off. The contracting core is a bomb ready to explode as soon as the helium ignites. Energy from the helium burning raises the temperature, but the temperature increase does not raise the pressure, so the reactions go faster and faster as the temperature shoots up. The resulting explosion, called the *helium flash*, is tremendous: For a short interval, the core of the star may produce as much energy as an entire galaxy! However, all of the energy is absorbed by the star, eventually forcing the core to expand and bringing the helium burning under control. To an outside observer, nothing about the giant star would even hint at the convulsive helium flash occurring at the core.

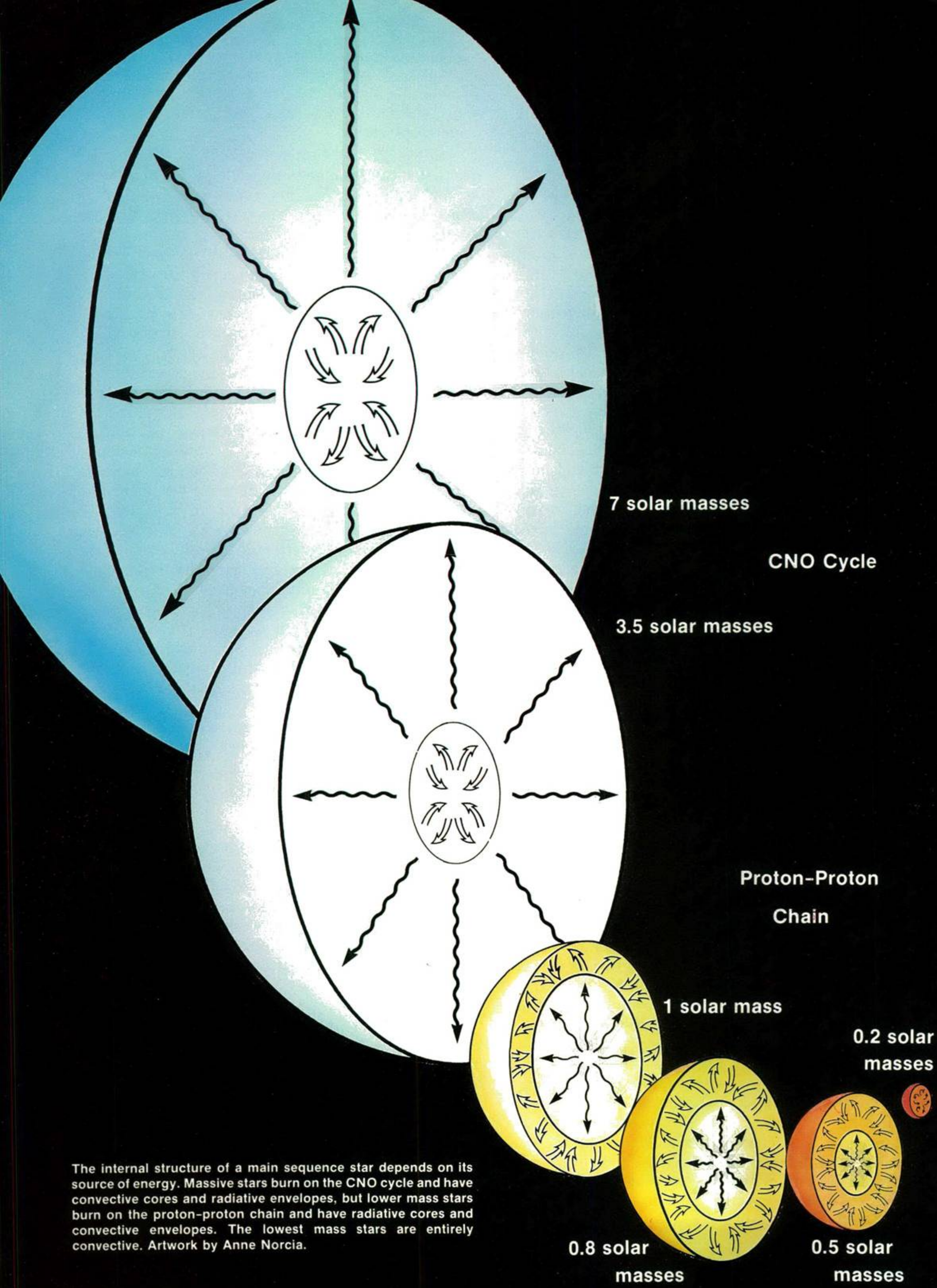
Not all stars experience the helium flash. Stars less massive than 0.4 solar masses never get hot enough to ignite helium. Stars with more than three solar masses begin to burn helium before the core becomes degenerate. Thus the pressure–temperature thermostat is in working order and keeps the helium burning under control. Only stars with masses between 0.4 and 3 solar masses experience the helium flash.

After the star ignites helium, it moves through a loop on the T–L diagram as it burns helium first in its core, and then in a shell. Throughout this loop the star continues to burn hydrogen in a shell outside the core.

Helium burning leaves behind a core of carbon and oxygen. As the helium shell burns outward, the carbon–oxygen core contracts and may ignite carbon burning if the temperature reaches 600 million degrees Kelvin. As in helium ignition, carbon ignition can be explosive if the core is degenerate, but carbon ignition is so violent it is called the *carbon detonation*. Some astronomers believe the carbon detonation may be strong enough to destroy stars in supernova explosions.

Not all stars experience carbon detonation. Stars less massive than three solar masses never get hot enough to ignite carbon, and stars more massive than nine solar masses ignite carbon before the core becomes degenerate. Therefore, although the sun will become a giant and will experience the helium flash, it will never face possible destruction by the carbon detonation.

The more massive stars are able to burn elements such as silicon and magnesium — elements left behind by carbon burning. Each time a fuel is exhausted, the star's core contracts and ignites the next heaviest fuel, first in the core and


7 solar masses
CNO Cycle
3.5 solar masses
Proton-Proton Chain
1 solar mass
0.2 solar masses
0.8 solar masses
0.5 solar masses

The internal structure of a main sequence star depends on its source of energy. Massive stars burn on the CNO cycle and have convective cores and radiative envelopes, but lower mass stars burn on the proton-proton chain and have radiative cores and convective envelopes. The lowest mass stars are entirely convective. Artwork by Anne Norcia.

then in a shell. This heavy element burning continues up to iron, but iron atoms are so stable they cannot burn in any nuclear reactions that produce energy. At this stage, the star has exhausted all possible fuels. Thus the development of an iron core is a disastrous condition that must lead to the star's death.

Stars die in two ways: Lower main sequence stars die gracefully, and upper main sequence stars die as supernova explosions.

The Graceful Deaths of Lower Main Sequence Stars

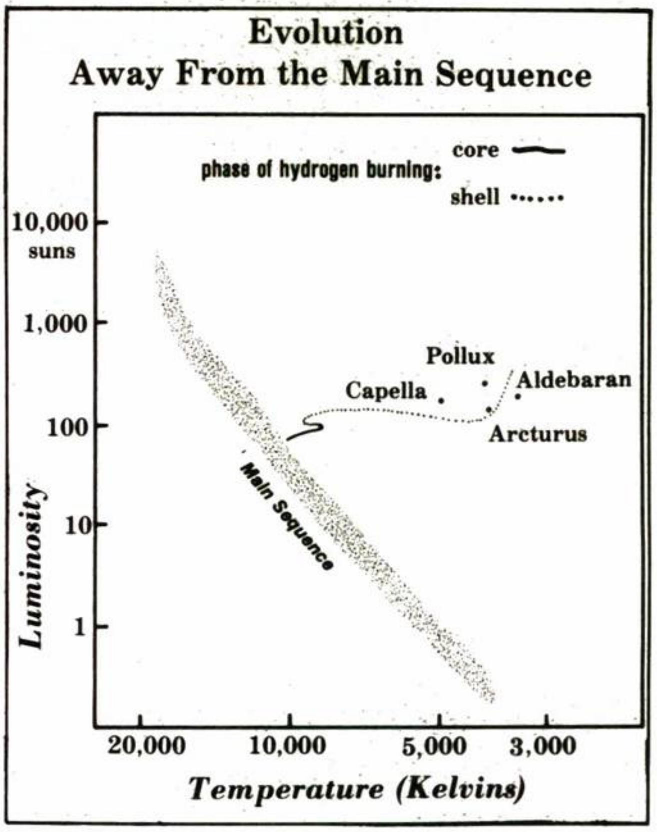
For our purposes, any star less than three solar masses is a lower main sequence star. Since these stars need little energy to support their weight, they use their fuel conservatively and live long lives. Those long lives are uneventful, since the stars can't get hot enough to ignite carbon and heavier atomic fuels. Lower main sequence stars divide naturally into two types: low mass stars that cannot ignite helium, and medium mass stars that can.

Stars less massive than 0.4 solar masses are convective throughout. Convection stirs their material and keeps composition uniform. Thus hydrogen burning at the center gradually depletes hydrogen uniformly throughout the star. When the hydrogen is exhausted and the star begins to contract, no layer of unburnt hydrogen exists to form a hydrogen burning shell. Without shell burning, the envelope does not expand and the star does not become a giant. Instead, it moves to the left on the T-L diagram as it contracts and grows hotter. Since gravitational energy can't heat the star enough to make it burn helium, nothing stops its contraction until the gas becomes degenerate. The star dies as a cooling white dwarf.

Medium mass stars have masses between 0.4 and 3 solar masses. These stars ignite a hydrogen burning shell, become giants, and then their contracting cores ignite helium. But when the helium is exhausted, the stars cannot get hot enough to ignite carbon. Instead, they eject their surface layers to form planetary nebulae.

No one is sure how such a star ejects its surface. Some astronomers suggest that instabilities develop in the helium burning shell, causing eruptions which may eject matter from the star. Others theorize that the giant star's surface becomes so cool that molecules form, absorb light, and make the surface layers relatively opaque. This dams up the flow of energy. The resulting pressure blows the surface off and forms an expanding shell of gas that we see as a planetary nebula.

Once the insulating surface layers are puffed into space, the stellar core collapses into a hot, small object called a planetary nebula nucleus. Its temperature can reach 100,000 degrees Kelvin. As the nucleus cools and the last nuclear reactions die away, it becomes a white dwarf.

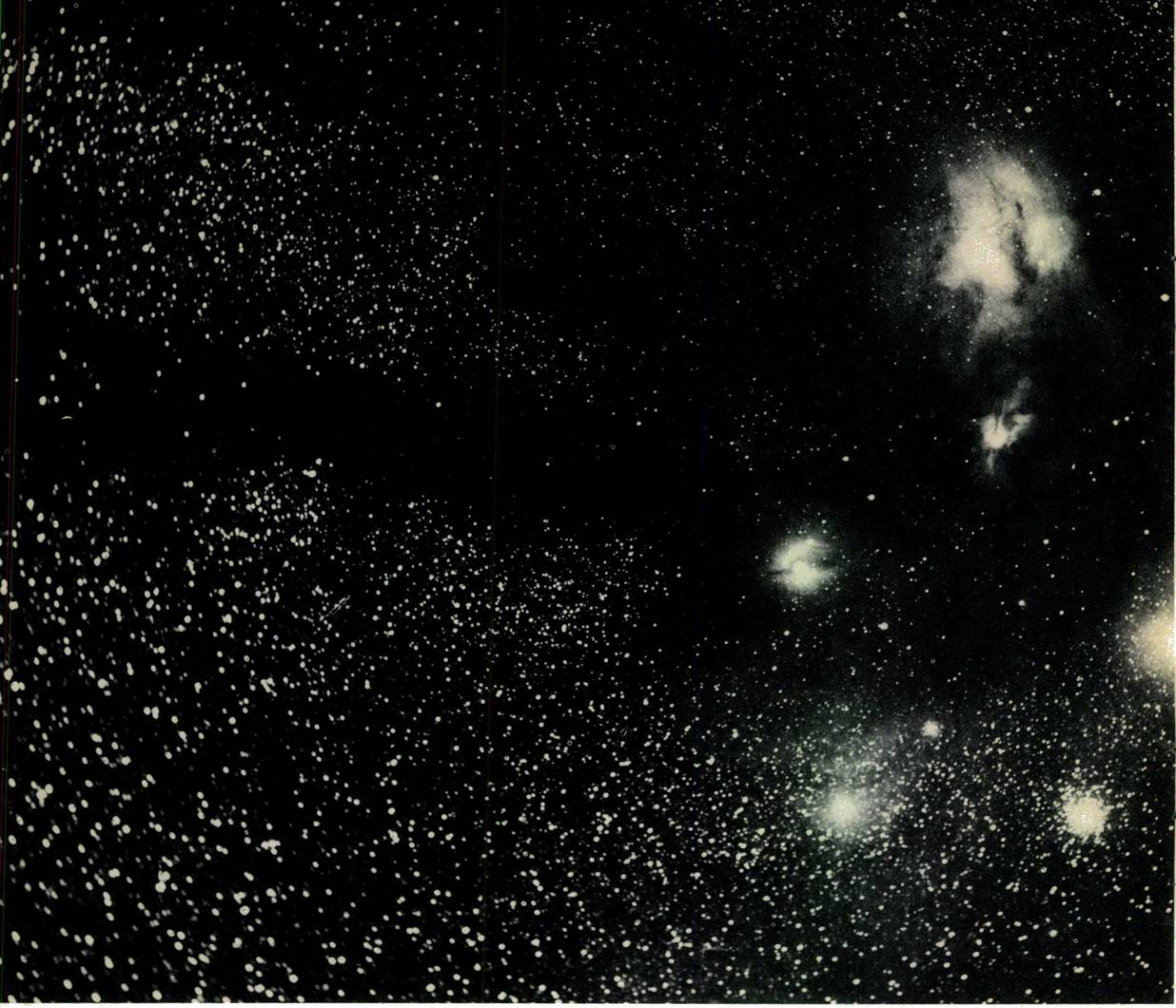


Stars move slowly off the main sequence as they burn the hydrogen fuel in their cores. Once shell burning begins, they move quickly into the red giant region of the temperature-luminosity diagram.

The evolution of both low and medium mass stars leads to white dwarfs — stars compressed into a volume slightly larger than that of Earth. A teaspoon of white dwarf material would weigh about 50 tons on Earth!

White dwarfs are not supported by nuclear reactions since they never get hot enough to ignite their remaining fuels. Instead, the gas becomes so dense the electrons resist further compression, and the star is supported by its degenerate gas pressure. As the star radiates energy, its temperature drops, but the pressure does not change. Thus the star cannot contract any further. Though it may take a few billion years, a white dwarf is destined to radiate its energy into space until it becomes a cold, dark, black dwarf.

Mathematical models of white dwarfs show that the radius depends on the mass: the more massive the white dwarf, the stronger its gravity and the smaller its radius. According to the models, a white dwarf of 1.4 solar masses has a radius of zero, and a more massive star cannot be a white dwarf. This upper limit to the mass of a white dwarf, called the *Chandrasekhar limit* (after the astronomer who discovered it), presents astronomers with a mystery. How do stars die if they are more massive than the Chandrasekhar limit? Certainly some shed mass in stellar winds (steady flows of gas analogous to our sun's solar wind), or by ejecting planetary nebulae. But what happens to those stars that don't shed enough mass?



To answer this question we must explore the deaths of upper main sequence stars.

The Deaths of Upper Main Sequence Stars

Stars more massive than three solar masses are capable of igniting carbon, and thus do not eject planetary nebulae and collapse to white dwarfs. But stars between three and nine solar masses face a more serious danger since their cores become degenerate before carbon ignites. The resulting carbon detonation (analagous to the helium flash) may blow the star apart in a supernova explosion. If stars survive the carbon detonation, they face the same ultimate fate of all massive stars — collapse and supernova.

After burning carbon, massive stars burn heavier and heavier elements up to iron. Iron burning, however, marks the beginning of the end. The iron core, lacking an energy source, contracts and grows hotter. Any nuclear reactions that occur involving iron absorb energy and make the contraction go faster. In addition, some nuclear reactions may produce neutrinos, massless, high energy particles that race out of the star at the speed of light carrying away energy needed to support the core. Thus if the core produces neutrinos, it will collapse even faster. The sudden collapse of the iron core allows the entire central region of the star to fall inward, generating tremendous heat and density, and leading to a supernova explosion.

Why the collapsing star explodes is one of the aspects of stellar evolution astronomers are still debating. One suggestion is that the center of the star becomes so degenerate it cannot contract further, and the infalling matter bounces off the degenerate core like a baseball bouncing off a brick wall. This bounce could eject stellar matter and trigger the explosion. Another important process is the ignition of unburnt atomic fuel that falls into the

The spaces between the stars are filled with material dense enough in some places to collapse gravitationally and become stars. The great dusty nebula near Rho Ophiuchi is illuminated in places where stars are embedded in it, and dark in other places where it can be seen only in silhouette. Regions like this one contain many faint, newly formed stars. Yerkes Observatory photograph.

core. If the infalling fuel is degenerate when it ignites, the lack of a pressure-temperature thermostat could trigger explosive burning. A third suggestion, based on computer models of supernovae, predicts that shock waves move outward through the star and smash through the outer envelope, compressing it and ejecting it from the star.

Whatever the process, supernovae become very luminous — the supernovae of 1054 A.D. was visible in the daytime for almost a month! Their high luminosity is due to the expanding shell of ejected matter, which has a large surface area and radiates tremendous amounts of energy. The luminosity shoots up for the first few days as the shell expands, and can become as bright as a billion times the luminosity of the sun. As the shell expands, it thins and cools, its luminosity declines, and the supernova finally fades from view.

The sites of past supernovae explosions are marked for tens of thousands of years by expanding shells of gas called supernova remnants. Some of these nebulae are stimulated to glow by ultraviolet radiation from the hot remains of the exploded star. Others are stimulated by the collision of the expanding shell with the surrounding interstellar medium. The Crab nebula in Taurus is an example of a young supernova remnant, formed only about 900 years ago by the supernova of 1054 A.D. The Veil nebula in Cygnus is a larger and older supernova remnant which originated about 50,000 years ago.

Neutron Stars

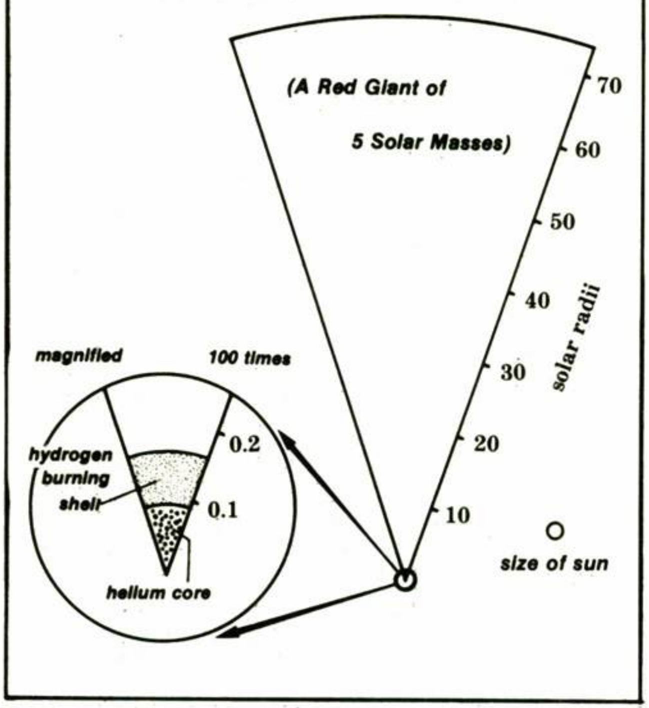
Though we have described supernova explosions, we have not answered our question: "What happens to a star with more than 1.4 solar masses when it collapses?" Theoretical models suggest that after the supernova ejects part of its mass, the remains collapse and, if the remaining mass exceeds 1.4 solar masses, becomes a neutron star or black hole. Which of these forms depends on the mass that collapses.

As the core of the supernova falls inward, the density becomes so great that even degenerate gas collapses. Matter is crushed to the point that electrons combine with protons to produce neutrons. This quickly transforms all the matter left by the supernova explosion into neutrons.If the mass of the collapsing object is less than three solar masses, the repulsion of the neutrons for each other is strong enough to balance gravity and stop the contraction. The resulting neutron star would be about 12 miles in diameter. Such a bizarre object probably contains a core of solid neutrons surrounded by a neutron superfluid and topped by a thin crystalline crust of neutrons and heavy atomic nuclei. On Earth, matter from the interior of a neutron star would weigh 50 billion tons per teaspoonful.

Theory predicts that neutron stars should spin rapidly and have intense magnetic fields. All stars rotate to some extent. As the core of a supernova collapses, it conserves angular momentum and spins faster. If the sun collapsed into a neutron star, its rotation would increase from once every 25 days to once every 0.001 second. The collapsing star should also concentrate whatever magnetic field it possesses into its new smaller volume. Since some stars have magnetic fields many times stronger than the sun's, the concentrated magnetic fields in neutron stars could be a billion to a trillion times stronger than the sun's.

These theoretical predictions match nicely with the radio observations of *pulsars* — objects

A Red Giant in Cross Section



A five solar mass star just before helium ignition is tremendously condensed toward the center — fully 12 percent of the star's mass is in the tiny helium core which occupies only three millionths of the star's volume. The envelope is a tenuous gas.

that emit precisely timed pulses of radio energy. Clearly, pulsars possess a powerful source of energy, for they have been detected not only at radio wavelengths, but also at the more energetic wavelengths of light and x-rays. These and other clues lead astronomers to believe that pulsars are spinning neutron stars.

The exact method by which a rotating neutron star produces pulses of radiation is not understood, but the best suggestion is termed the *lighthouse theory*. Suppose that the magnetic axis of the rotating neutron star is not aligned with its axis of rotation. Radiation leaving the neutron star could be focused into beams emitted from the magnetic poles. The rapid rotation of the neutron star would sweep these beams around the sky like the beams from a lighthouse, and astronomers on Earth would receive a pulse of radiation every time the beam swept by.

Two properties of pulsars suggest that the lighthouse theory is correct. First, many pulsars are slowing down by a few billionths second per day. Though this is a small change in the pulse rate, atomic clocks can mark the rate of decrease accurately. The amount of energy a pulsar radiates into space per day is approximately equal to the amount of energy a spinning neutron star loses by slowing down a few billionths of a second. Thus it seems the spinning neutron star and its intense magnetic field somehow convert energy of rotation into electromagnetic radiation.

A second property of pulsars that supports the lighthouse theory is the sudden increase in the pulse rate. Such a change is called a *glitch*. The first glitch was discovered when the pulsar known as the "Vela pulsar" suddenly increased its pulse rate by 200 billionths of a second in early March 1969. Since then a few more glitches have been observed in both the Vela and Crab pulsars. The lighthouse model explains these changes by supposing that as the spinning neutron star slows down, stresses build up within its crystalline crust. Eventually the crust fractures, and the neutron star shrinks slightly. As it contracts, the conservation of angular momentum makes it spin faster, increasing its pulse rate.

Since we know the Crab nebula is the remains of a recent supernova, and since we suspect that supernovae sometimes leave behind neutron stars, the discovery of a pulsar blinking at the heart of the Crab nebula is accepted as a vital connecting link between the theoretical neutron stars and the observational pulsars. Two other properties of the Crab nebula pulsar confirm its recent origin in the supernova of 1054 A.D. First, it is the fastest known pulsar, blinking 30 times per second. This high pulse rate is evidently a product of its youth — it formed only 900 years ago and hasn't slowed down very much. Second, its pulses are visible as light and x-rays. Circumstantial evidence suggests that this second property is also connected with the pulsar's youth. The only other pulsar known to emit light pulses is the Vela pulsar, a fast pulsar thought to be young. Evidently when a pulsar forms, it spins rapidly and may have enough energy to emit short wavelengths such as light. As it grows older, it slows down, and, having less energy of rotation, is not able to emit light. The pulsar in the center of the Crab nebula fits this pattern.

The connection between neutron stars, pulsars and the supernova death of massive stars seems solid, even though most pulsars are not found inside supernova remnants, and most remnants do not contain pulsars. Some remnants probably contain spinning neutron stars whose beams never sweep over Earth, and some pulsars probably move out of their supernova remnants. Many pulsars are so distant that their supernova remnants would be obscured by intervening dust clouds. Even those pulsars that are nearby may lack surrounding remnants, because the expanding gases dissipate in a few tens of thousands of years, while the pulsar can continue pulsing for millions of years. A few remnants may lack pulsars because the supernova explosion left behind too much mass and formed a black hole instead of a neutron star.

Black Holes

If the mass of the collapsing core exceeds three solar masses, even the repulsion between neutrons cannot support the weight of the star. The collapse continues: In a fraction of a second the object becomes smaller than an atom, and continues to shrink until it reaches zero radius. Such an object,

Round and perfect as a Christmas tree ornament, the planetary nebula NGC-6781 attests to a sudden eruption that "bounced" the surface layers right off its parent star. Planetary nebulae result when medium mass stars such as our sun deplete their supply of helium and, unable to burn elements any heavier, eject their outer layers. Photograph copyright © 1965 by California Institute of Technology and Carnegie Institution of Washington.

known as a *singularity*, is nearly beyond our comprehension. Nevertheless, no one knows of anything that could stop the collapsing star from becoming a singularity.

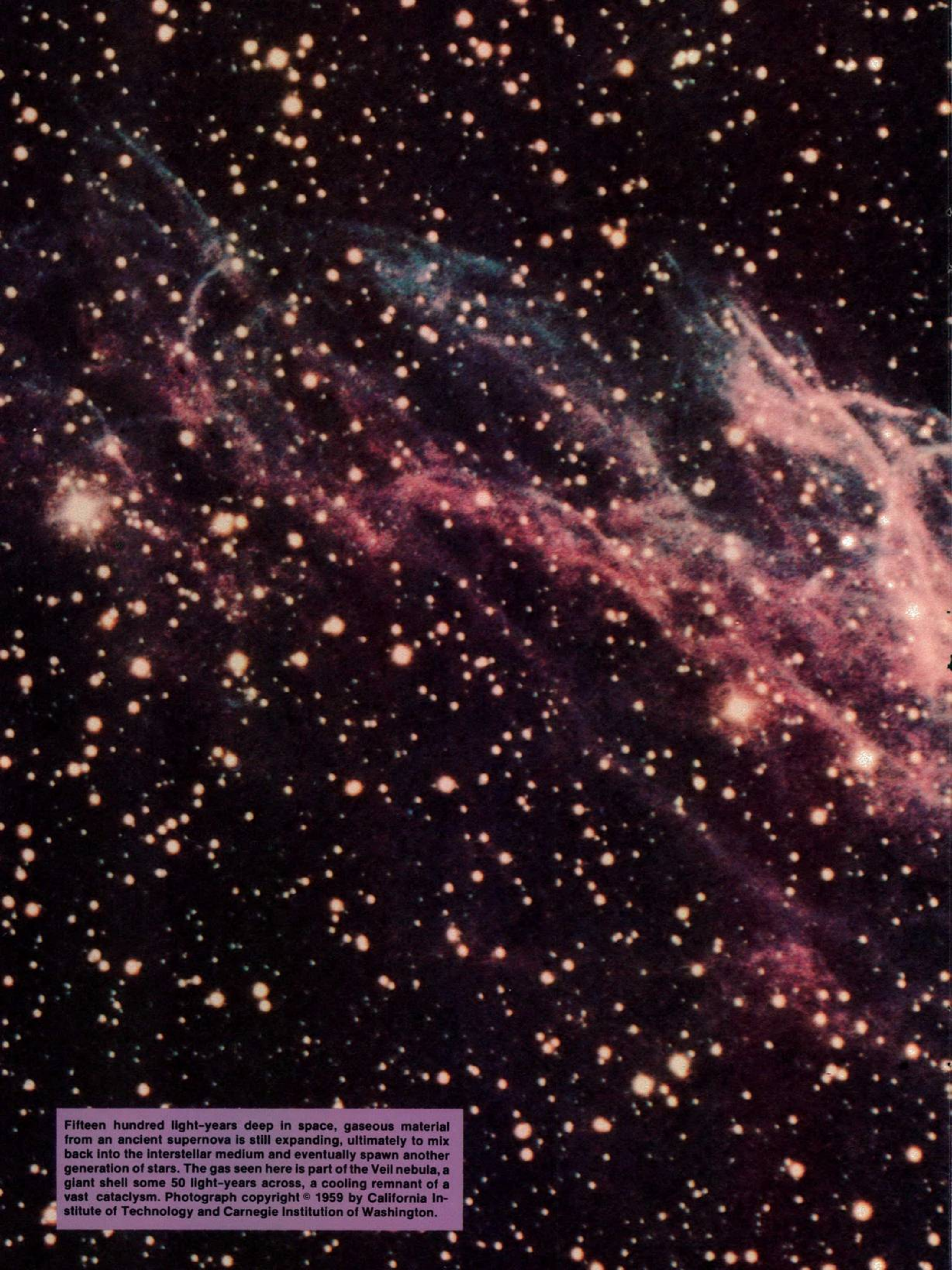
Within a small sphere around the singularity, gravity is so intense that nothing — not even light — can escape. Since we receive no signals from this region of space, we call it a black hole. The "surface" of this region is called the *event horizon*. Any event that occurs inside the event horizon is invisible to us, and anything that falls into the black hole must vanish as soon as it crosses the event horizon.

The best evidence that black holes exist lies in an object called Cyg X-1, the first x-ray object discovered in Cygnus (see "Are Black Holes Really There?" in the October 1978 issue). Spectra of Cyg X-1 reveal it to be a binary star system in which a large hot star orbits around a small object that radiates little or no light. The large star emits a stellar wind of tenuous gas, some of which gets caught in the gravitational field of the small object and is drawn in. Since the gas must conserve angular momentum, it cannot fall in directly, but forms a whirling ring called an *accretion disk*. This disk is about two million miles in diameter. As matter in the disk orbits the central object, friction slows it, heats it, and it spirals gradually toward the center. The inner parts of the disk can become as hot as 10 million degrees Kelvin and emit the x-rays detected on Earth.

The fact that Cyg X-1 emits x-rays does not prove it is a black hole. The small object could be a neutron star. A number of x-ray binaries are known to contain neutron stars. Cyg X-1, however, is special since the orbital motion of the system reveals that the small object has a mass around nine solar masses. This is too massive to be a neutron star. We can eliminate normal stars since they are too large to form such hot accretion disks. The only possibility left is a black hole. A similar system, V861 Scorpii, is an x-ray binary with a small object of more than five solar masses, and it too may be a black hole. Thus at least two black holes are, by circumstantial evidence, known to exist, and give astronomers confidence in their theories of stellar evolution.

The Star Cycle

Our study of stellar evolution reveals four important principles: *1)* The evolution of a star is dominated by its gravity. Whatever fuels it burns, however it expands and contracts, it can only delay



Fifteen hundred light-years deep in space, gaseous material from an ancient supernova is still expanding, ultimately to mix back into the interstellar medium and eventually spawn another generation of stars. The gas seen here is part of the Veil nebula, a giant shell some 50 light-years across, a cooling remnant of a vast cataclysm. Photograph copyright © 1959 by California Institute of Technology and Carnegie Institution of Washington.

its inevitable end. *2)* The more massive a star is, the faster it evolves and dies. *3)* The star making process concentrates matter in three end states — white dwarfs, neutron stars and black holes. Although stellar winds, planetary nebulae, and supernova remnants return some matter to the interstellar medium, most of the mass is trapped in the end states. *4)* Stellar evolution converts light elements into heavy elements.

These four principles permit us to understand how the cycle of star formation and death gradually alters a galaxy. The galaxy begins as a cloud of gas, mostly hydrogen and helium. There are very few heavy atoms in the gas because there have been no stars to manufacture heavy elements. The first stars to form are thus poor in heavy atoms. Most of these are low mass stars that live long times and never supernova; a few, however, are massive and quickly manufacture heavy atoms, then explode as supernovae. They pollute the hydrogen/helium interstellar medium with a trace — just a few percent — of heavy elements.

The oldest stars in our galaxy, called *Population II* stars, are the low mass remains of this early generation. Spectra of these stars show weak heavy element lines. During the 10 billion years since their formation they have manufactured some heavy elements in their cores, but for the most part these atoms remain trapped within the centers of the stars. The surface composition is essentially unaltered and reflects the low abundance of heavy element in the galaxy when the stars formed.

Each generation of stars forms from clouds of gas more enriched with heavy elements. Middle aged stars like the sun formed a few billion years ago from gas clouds that contained about two percent heavy elements. Stars forming right now, like those in the Orion nebula, include about four percent heavy elements.

The star cycle will go on forming new stars with greater heavy element concentration, but it cannot go on forever because each generation traps most of its mass in white dwarfs, neutron stars, and black holes. Eventually all the matter will be trapped in stars, stopping the formation of stars. The last of the massive stars die quickly, while the lower mass stars remain, though they too must eventually die. The lowest mass stars can live for hundreds of billions of years, but — assuming the universe lasts that long — they too must exhaust their fuel and die. That will be the end of the star cycle, the end of stellar evolution, and perhaps the end of everything.

Michael Seeds is an assistant professor of astronomy at Franklin and Marshall College in Lancaster, Pa. His primary research interest is photoelectric photometry of Beta Cephei and Delta Scuti stars — types of variable stars that may offer insights into stellar evolution. He is currently working on an introductory textbook for Wadsworth Publishers, due to appear in the fall of 1980.

SKY ALMANAC

The Sun Will Darken!

Mention the "dead of winter" and most people think of February! It's hard these nights to get much observing done — simply staying unfrozen seems to take all your efforts. But if you do go out on these clear frosty nights, you'll have a lot of magnificent things to see! Jupiter is visible early, Saturn appears only a bit later and Venus is still greeting the dawn. You can see another in the Aldebaran occultation series, and even the sun gets occulted late in the month, so don't let the elements set you back! (For details about the eclipse, see the November 1978 issue of ASTRONOMY!)

Mercury

Swift little Mercury will be very close to sun in the sky for the first part of the month as it passes through superior conjunction on the 9th at 6^h UT. Don't despair of finding it, though, for you'll catch a glimpse of it in the evening sky as it speeds toward eastern elongation (on March 8). Look for it at magnitude -1.0 low in the west on the 25th. On that date it'll be about seven degrees high in the west southwest (azimuth 260 degrees) 1/2 hour after sundown.

If you train your telescope on it, you'll spy a tiny disk 5.5 seconds of arc in diameter swimming in the haze, and about 80 percent lit.

This evening apparition will be a swift one, so don't dawdle in looking for it! (A diagram showing altitude and azimuth was published in the December 1978 Gazer's Gazette.)

Venus

Venus continues to dominate the morning skies throughout the month. Its movement in the sky will be mainly to the north in azimuth, while its elevation 1/2 hour before sunrise remains constant at about 10 to 12 degrees.

A telescope will reveal to you Venus' phases, first seen by Galileo in the early 17th century. On the 1st, Venus will have a gibbous disk 22 seconds of arc in size and 57 percent lit. By the 28th, the size will have shrunk to 17 seconds, while the phase will have grown to 67 percent. During February, as the planet moves away from us, you'll see it drop 1/5 magnitude (from -3.9 to -3.7).

Moon

In the late afternoon to early evening of the 5th, the moon, a day past first quarter, will occult Aldebaran. The northern limit for the occultation runs across the United States and Canada in an approximate southwest to northeast direction from the California coast south of San Francisco. Moving toward the northeast, the limit line runs across Utah, Wyoming, South Dakota, and northeast Minnesota into northern Ontario near Lake Nipigon. The line then cuts across southern James Bay and northern Quebec.

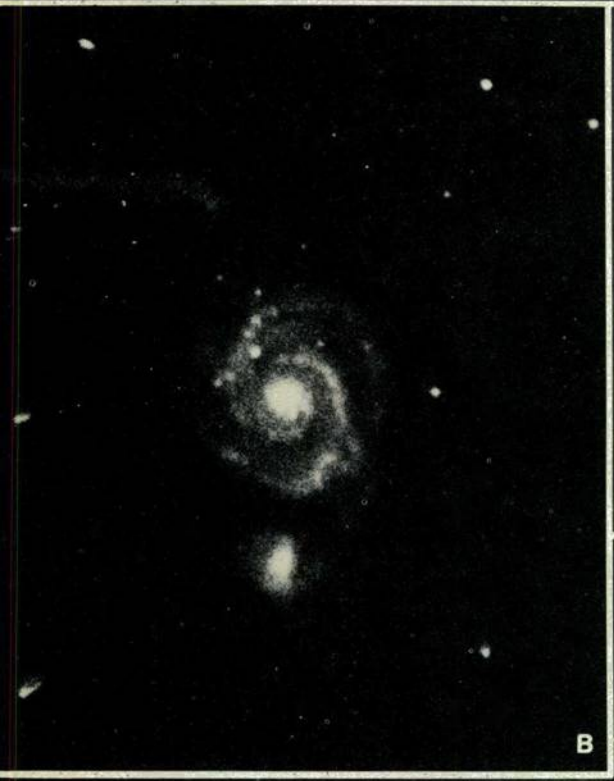
The occultation will be a favorable one, since the disappearance happens on the dark limb. In the Upcoming Events for February (published last month), we gave the times for various stations. At your location, the time of disappearance will be slightly different, so use the times given for stations in your vicinity as a guide. We've said it before and we'll say it again: The universe waits for nobody, so be out there and set up *early!*

People living on the northern limit line may see a grazing occultation — an exciting event where the star (or planet, as happens sometimes) ducks in and out behind the mountains on the limb of the moon!

First quarter: February 4th, at 0^h36^m UT, in Aries. Full moon: February 12th, at 2^h39^m UT, in Leo. Last quarter: February 20th, at 1^h17^m UT, in Scorpio. New moon: February 26th, at 16^h45^m UT, in Aquarius.

The central portions of the moon show clearly in this view taken near first quarter. The dark patch to the upper left is Mare Fecunditatis; in the lower center lies Mare Tranquillitatis, the site of the first manned lunar landing, and at bottom center is Mare Serenitatis. Photograph by Jiri Bunata.

A



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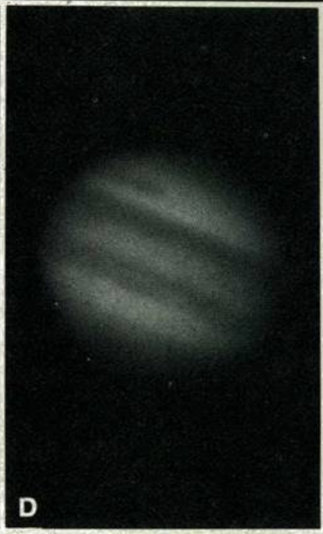

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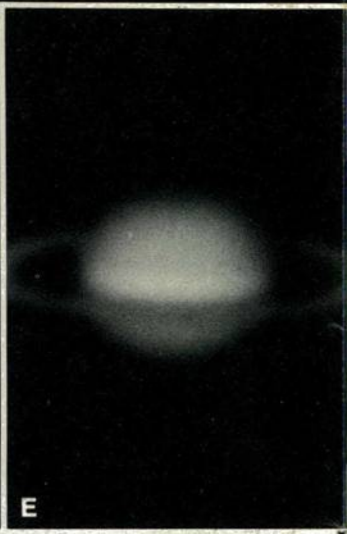


E

F

A: Almost one entire lunation! (photograph by L. H. Price) **B:** M-51, the Whirlpool galaxy (Robert Luffel) **C:** Venus, near quadrature (Ron Gattie) **D:** Jupiter (A. Stulginskas) **E:** integration print of Saturn (Thomas Rotkiewicz) **F:** the famous Horsehead nebula and Zeta Orionis (Lee C. Coombs) **G:** aurora of Aug. 27, 1978 seen from near Spokane, Wash.; the bright star at right center is Vega. (Larry Evans)

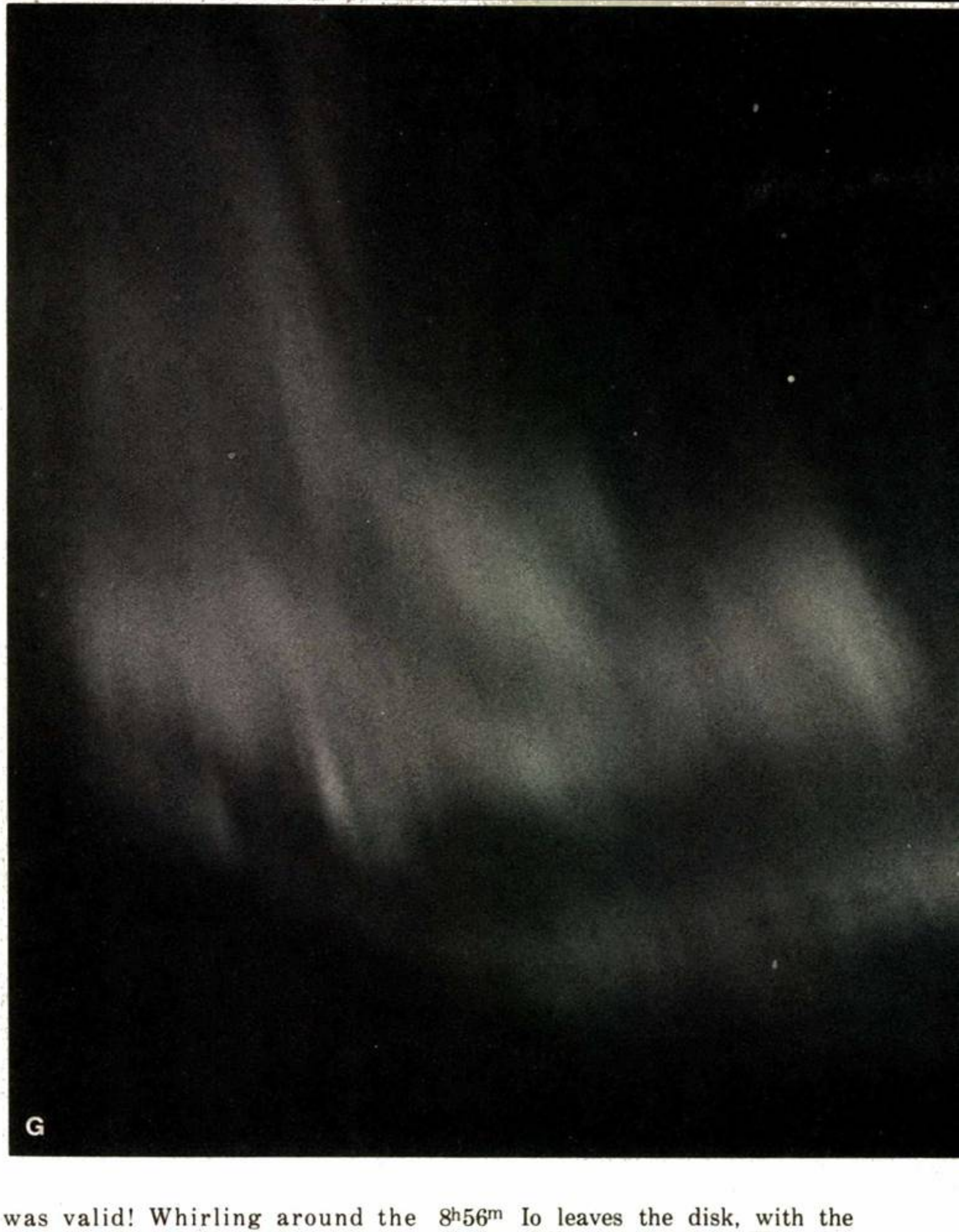
Upcoming Events for March

1 Saturn at opposition
5 Occultation of Aldebaran
First Quarter Moon
8 Mercury at greatest eastern elongation
13 Full Moon and partial eclipse
21 Vernal equinox (spring begins)
Last Quarter Moon
24 Mercury at inferior conjunction
28 New Moon

The opposition of Saturn places it in the sky for observation the whole night.

The occultation of Aldebaran won't be one for most of our readers. Only those in the southern half of California will see it, and even for them the moon's elevation will be low at the time (8^h08^m UT).

The partial eclipse is an event for those in western Asia and Europe, but not North America.



Mars

Tiny, ruddy Mars slowly draws away from the sun's glare into the morning sky. You'll have some difficulty finding the four arc second dot (magnitude +1.3) in the bright twilight.

Jupiter

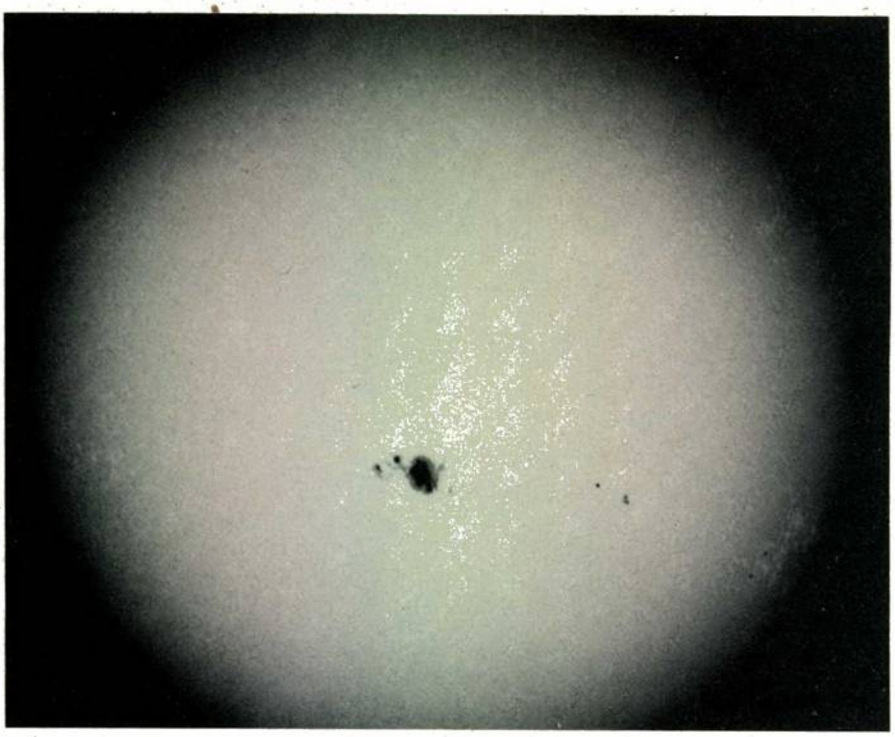
Jupiter's retrograde (westward) loop in the sky is taking it ever farther from the Beehive cluster, but you'll have no trouble finding the -2.1 magnitude "star"!

On any night, you can enjoy the captivating array of phenomena displayed by the four chief moons. You'll soon see why Galileo felt the Copernican theory of the solar system was valid! Whirling around the massive planet, the moons seem to mimic the sun's family of planets.

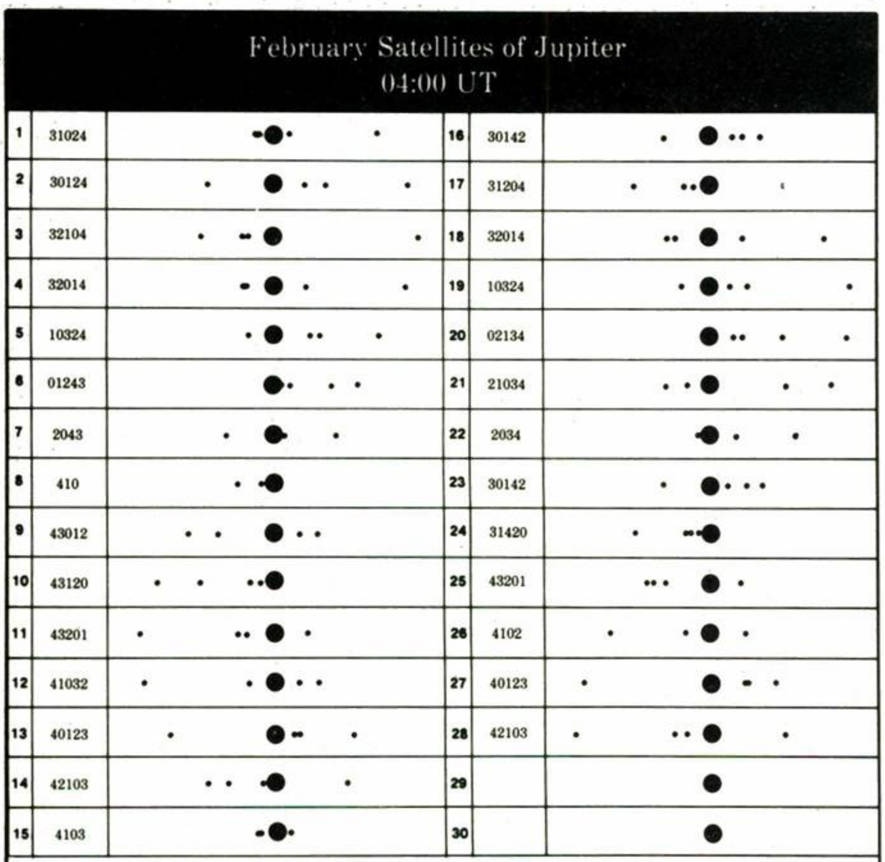
On the the morning of the 6th, you'll be able to watch satellites I and II (Io and Europa) cross the disk of Jupiter, followed shortly by their shadows. Io starts over the disk at 6^h40^m UT, its shadow pursuing it at 6^h58^m. Europa begins to cross at 7^h34^m, while its shadow doesn't follow until 8^h13^m. At 8^h56^m Io leaves the disk, with the shadow following at 9^h14^m. The same events happen for Europa and its shadow at 10^h27^m (moon) and 11^h06^m (shadow). Watch for them!

Saturn

Still in southern Leo, Saturn rises around 8 p.m. Look for the object about one magnitude brighter than Regulus, and about halfway between it and Denebola, the star at the tail of the lion.



Above: Typical of the current level of solar activity, this photo shows a massive sunspot, the bright irregular faculae and pronounced limb darkening. At times of steady seeing, granulation cells also can be seen covering the whole surface. Photograph by Andrew W. Steinbrecher.



February Satellites of Jupiter
04:00 UT

1	31024	16	30142
2	30124	17	31204
3	32104	18	32014
4	32014	19	10324
5	10324	20	02134
6	01243	21	21034
7	2043	22	2034
8	410	23	30142
9	43012	24	31420
10	43120	25	43201
11	43201	26	4102
12	41032	27	40123
13	40123	28	42103
14	42103	29	
15	4103	30	

The four major satellites of Jupiter orbit the planet in periods ranging less than 2 days to 17 days. You'll see them change position from night to night. This table shows the approximate position of the moons each night. The column at the far left shows the date; the second column gives the names of the moons (Jupiter = 0, Io = I, Europa = 2, Ganymede = 3, Callisto = 4). The third column shows the satellites' positions as they appear through an inverting telescope; south is at the top.

Universal Time

Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times given in Sky Almanac are in UT unless noted otherwise. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 UT on Jan. 2, then the time in EST would be 10 p.m. Jan. 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m. on March 4.

You'll have no trouble spotting the planet, for the sky is relatively dim in its region. A telescope with low to moderate powers will show the glorious spectacle of the rings. (Uranus also has rings, but since they're undetectable by eye, they don't really count for the average observer.)

Saturn's rings will present a curious variety of shapes this year because we're now seeing them almost edge-on. From now until the last week in April, the rings will appear to open up until they reach a maximum of almost six degrees. Thereafter they'll slowly close up once more until Earth passes through the plane of the rings on Oct. 27. During the last passage (in 1966), the tiny inner moon Janus was discovered. Will still another satellite be found? We'll just have to wait and see!

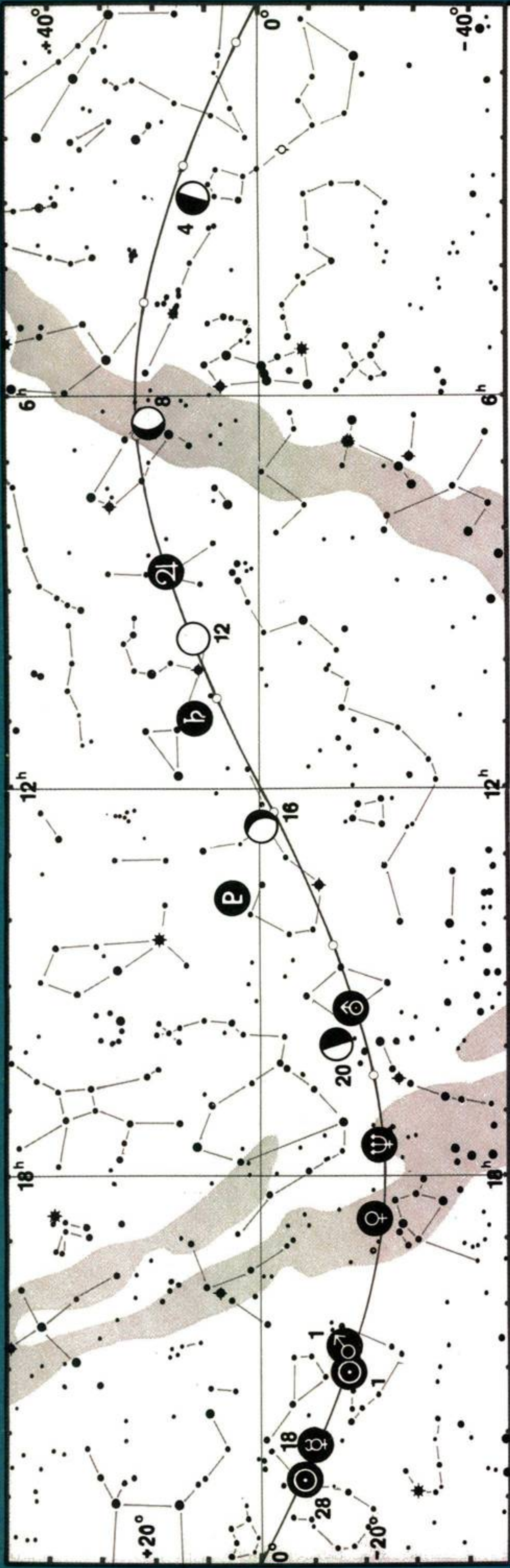
Uranus

Uranus' slow eastward motion will come to a halt on the 24th, as Earth begins to overtake it. Uranus will then continue to move westward until July 26, when it'll stop and then resume eastward motion again.

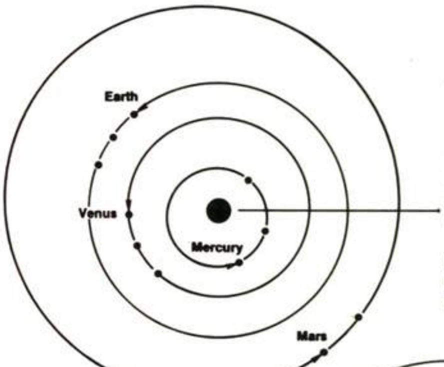
Although it rises around 1 a.m., you'd do best to wait until the hours before dawn to look for it. If you plan to observe Venus some chilly morning, look for Uranus as well! On the 1st and 2nd of the month, you'll find it very close to 6.3 magnitude 26 Librae. With your telescope, look about two degrees to the north of Iota Librae (magnitude 4.5), and you'll soon pick out the dim star and slightly brighter planet. Uranus' disk will be 3.7 seconds of arc in diameter.

Neptune

Neptune is still close to sun this month, making observations difficult. Hunt for it with a telescope. Binoculars can be used, but since the image will look stellar, positive identification is hard. Search for it one degree or so to the southwest of Xi Ophiuchi, an orange star of 4.5 magnitude. You'll discern Neptune by its diminutive disk just 2.4 seconds of arc across.

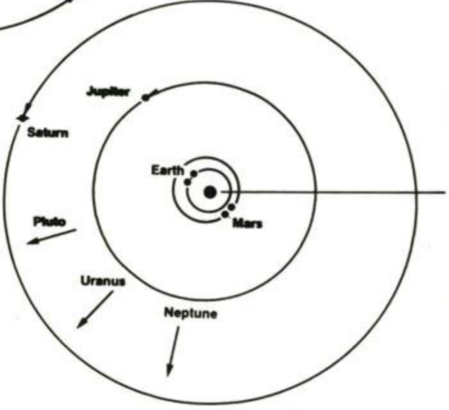

+40°
0°
-40°
4
6h
8
6h
12
12h
16
12h
20
18h
18h
1
1
18
28
+20°
0°
-20°

Planet Finder

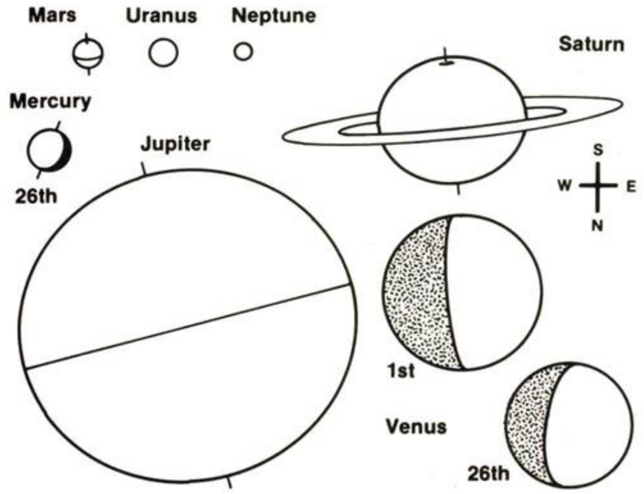

Earth
Venus
Mercury
Mars

The positions of Mercury, Venus, Earth and Mars in their orbits are shown for the beginning, middle and end of the month. (Mars for the beginning and end only). The vernal equinox is the line at right.

The orbits of Earth, Mars, Jupiter and Saturn are shown at right. Earth and Mars' positions are for the first and last of the month; Jupiter and Saturn for mid-month. The outermost planets' directions are indicated.


Jupiter
Saturn
Earth
Pluto
Mars
Uranus
Neptune

Planet	Date	R.A. (1979.2)	Dec.	Mag.	Dist. (AU)
Mercury ☿	18	$22^h32.6^m$	-10°47.8′	-1.2	1.32
	22	$22^h59.7^m$	-7°32.3′	-1.1	1.26
	26	$23^h25.5^m$	-4°06.0′	-1.0	1.18
Venus ♀	10	$18^h21.9^m$	-20°51.3′	-3.9	0.84
	30	$19^h10.4^m$	-20°37.1′	-3.8	0.92
Mars ♂	15	$21^h30.5^m$	-15°53.2′	+1.3	2.37
Jupiter ♃	15	$8^h14.9^m$	+20°31.5′	-2.1	4.37
Saturn ♄	15	$10^h55.6^m$	+9°01.9′	+0.6	8.37
Uranus ⛢	15	$15^h14.5^m$	-17°40.1′	5.7	18.56
Neptune ♆	15	$17^h17.5^m$	-21°40.6′	7.7	30.68
Pluto ♇	15	$13^h35.3^m$	+8°52.3′	14.0	29.70


Mars
Uranus
Neptune
Saturn
Mercury
26th
Jupiter
S
W
E
N
1st
Venus
26th

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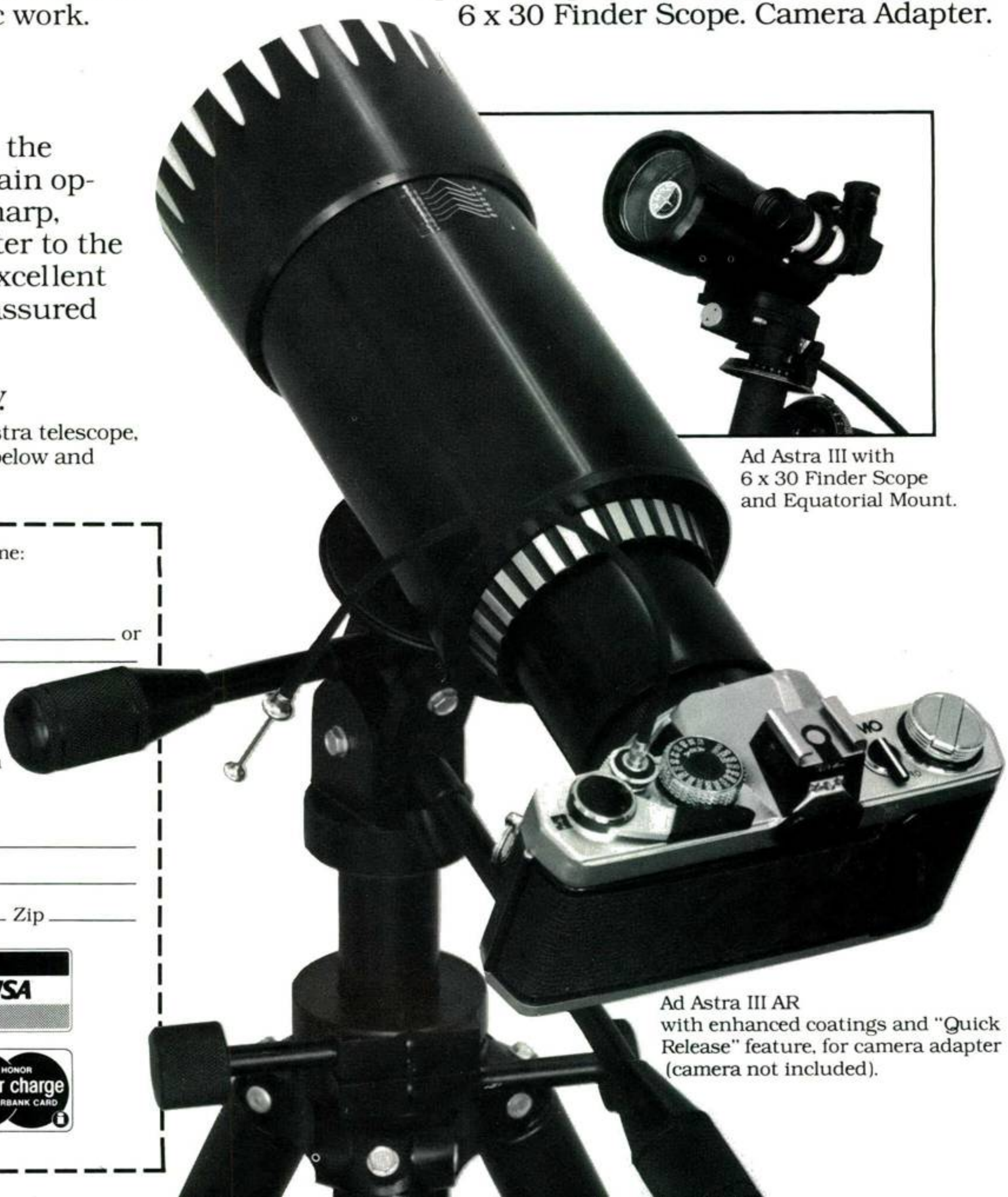

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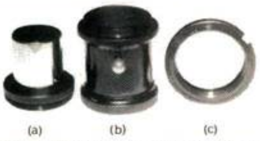

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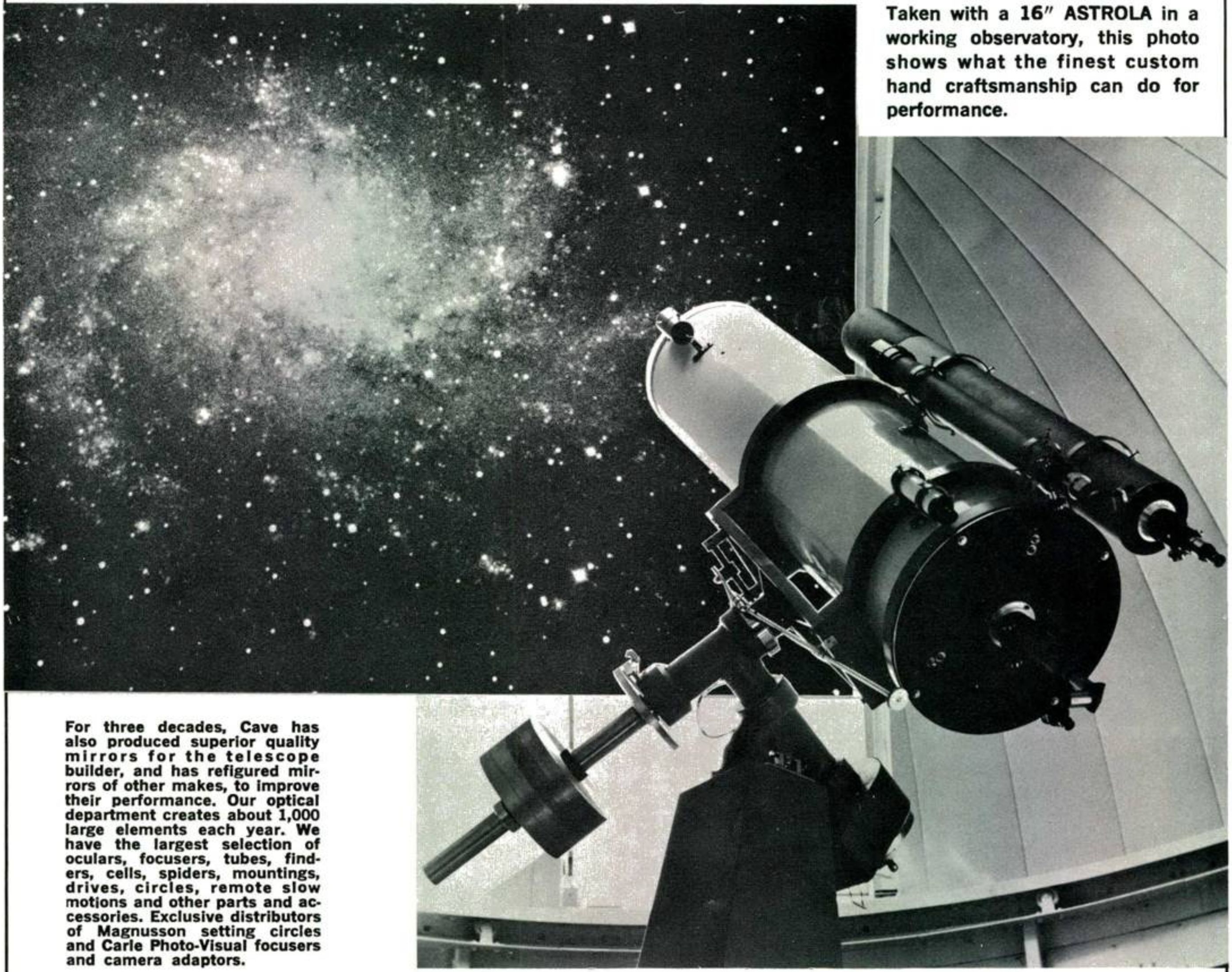

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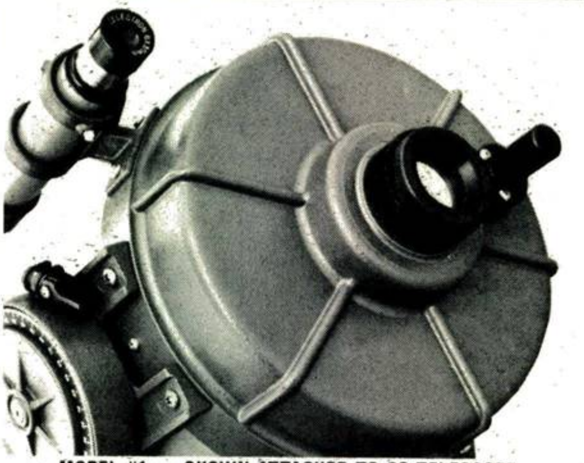
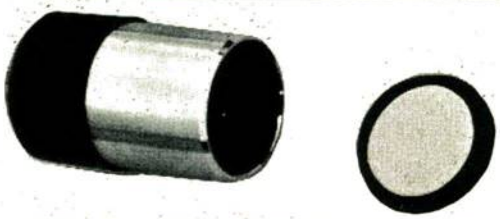


MODEL #1 — SHOWN ATTACHED TO C8 TELESCOPE



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Average Transmission of Stellar Sources — 70%

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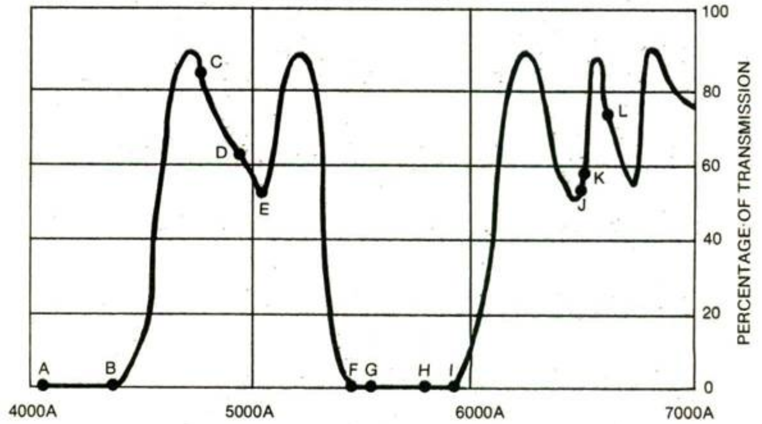

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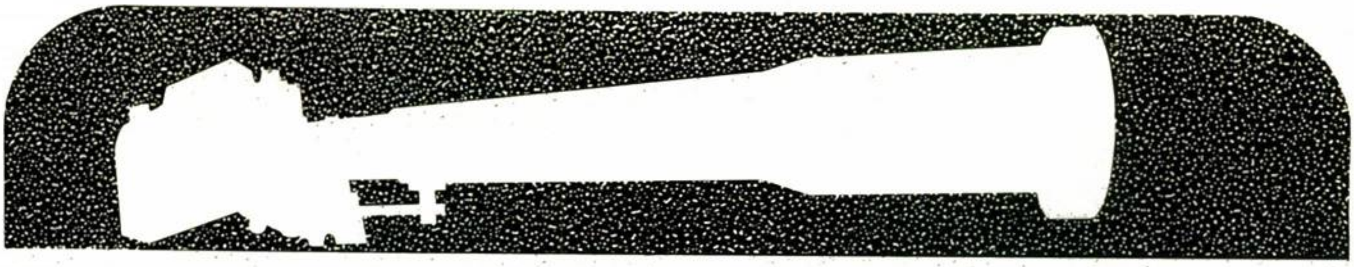


PHOTOGRAPHY IN ASTRONOMY

Improve Your Slides Through Rephotography

by
Ben Mayer

With newer and faster color films, more astrophotographers than ever are trying their hand at color photography. With the advent of Kodak's ASA 400 Ektachrome — "Tri-X with ultimate realism" — stars in their many hues appear realistically portrayed in the velvet blue-black field of the night sky; variables stand out in easy-to-spot reds, and emission nebulae glow in various shades of pink and magneta. No longer is it necessary to guide endless long exposures to achieve worthwhile results.

But there is an additional way to make color transparencies even more dramatic — a method to convert faint (but otherwise meaningful) slides into dramatic records. It's called *rephotography.*

Rephotography need involve no more than a set of extension tubes for your camera's standard 50mm lens. Using your tripod mounted camera, you can simply move in close to shoot an existing slide, lit from behind. Bellows available for most camera systems make the task even easier. Again, daylight makes an almost ideal light source to illuminate the transparency to be photographed. The next step up in enhancing the quality of the results is to use the macrolenses with flat fields provided with commercial slide copiers. Offering the ultimate in speed and control, some of these units include preset, built-in flash lighting. But for the easiest and quickest results, it is sufficient to return your original to the lab and to have them make a duplicate transparency for you.

There are a variety of advantages doing the work yourself, however. Not only does rephotography produce notable increases in contrast — making colors of stars more pronounced, and pushing imperceptible traces of hydrogen clouds into easily visible formations — but the process also permits you to crop and recompose your photographs. For example, if finding a guide star posed a problem during original exposure, you might have placed the object itself off-center — even in a corner. Through rephotography, it can be restored to its rightful place in the center of the picture, and can even be enlarged without undue degradation.

Rephotography is done with slow film. An ideal emulsion is Kodachrome 25, a film with excellent color reproduction qualities and fine grain. Since daylight or a daylight-simulating flash is used, the film is put to work under its own optimum conditions. The results speak for themselves.

For anyone working with 120 format film, cold cameras, or a combination of both, the original slide becomes an item of considerable value because of the time and effort spent taking it. To be able to share such a photograph with others — without risking the original — copying the master slide is almost a necessity. So why not turn this necessity into an

You Can Also Rephotograph in Black and White

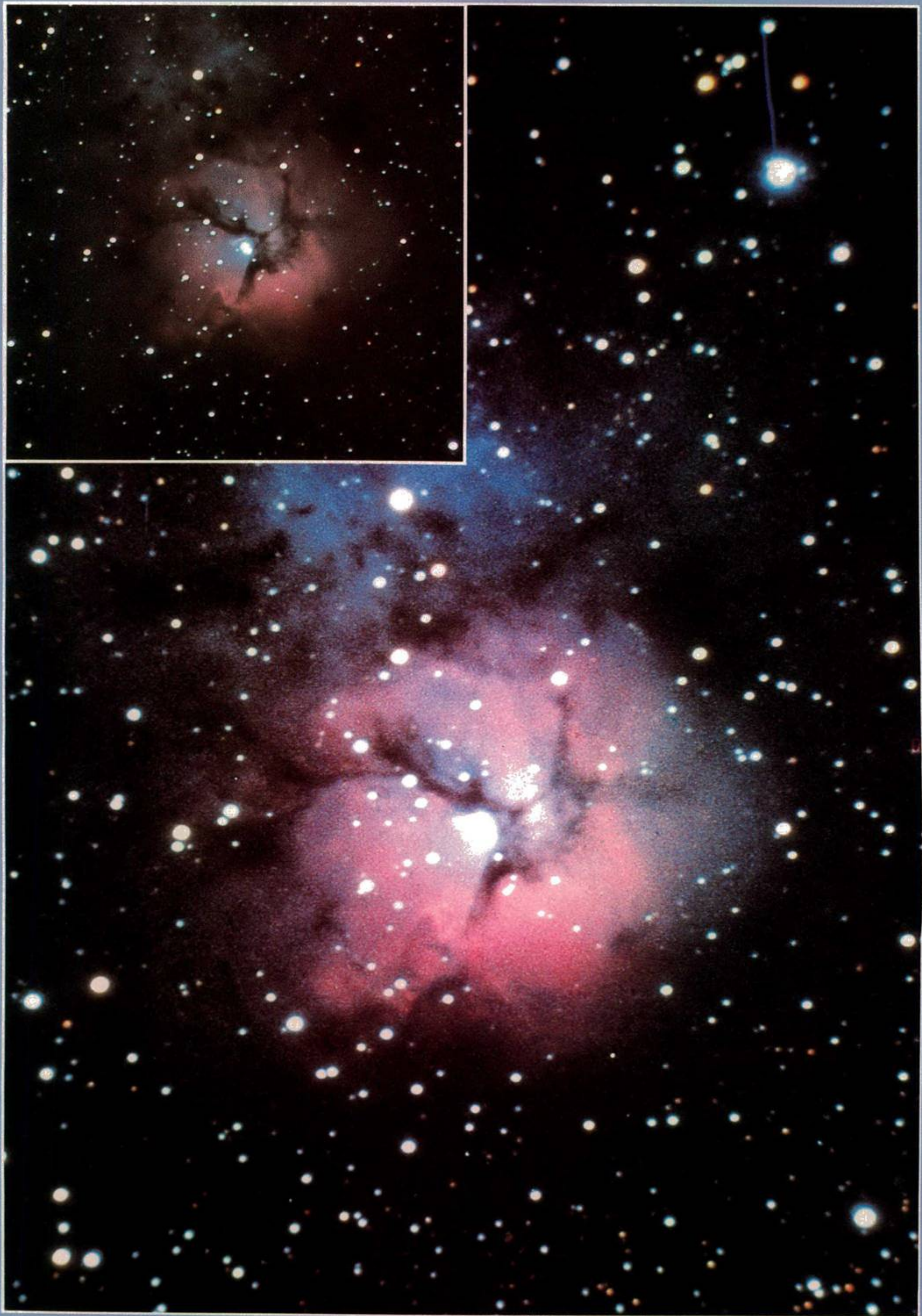
Most of the time you'll want to rephotograph color originals on color film. But occasionally, in order to bring out faint or extraordinarily low contrast details, you may want to try black and white.

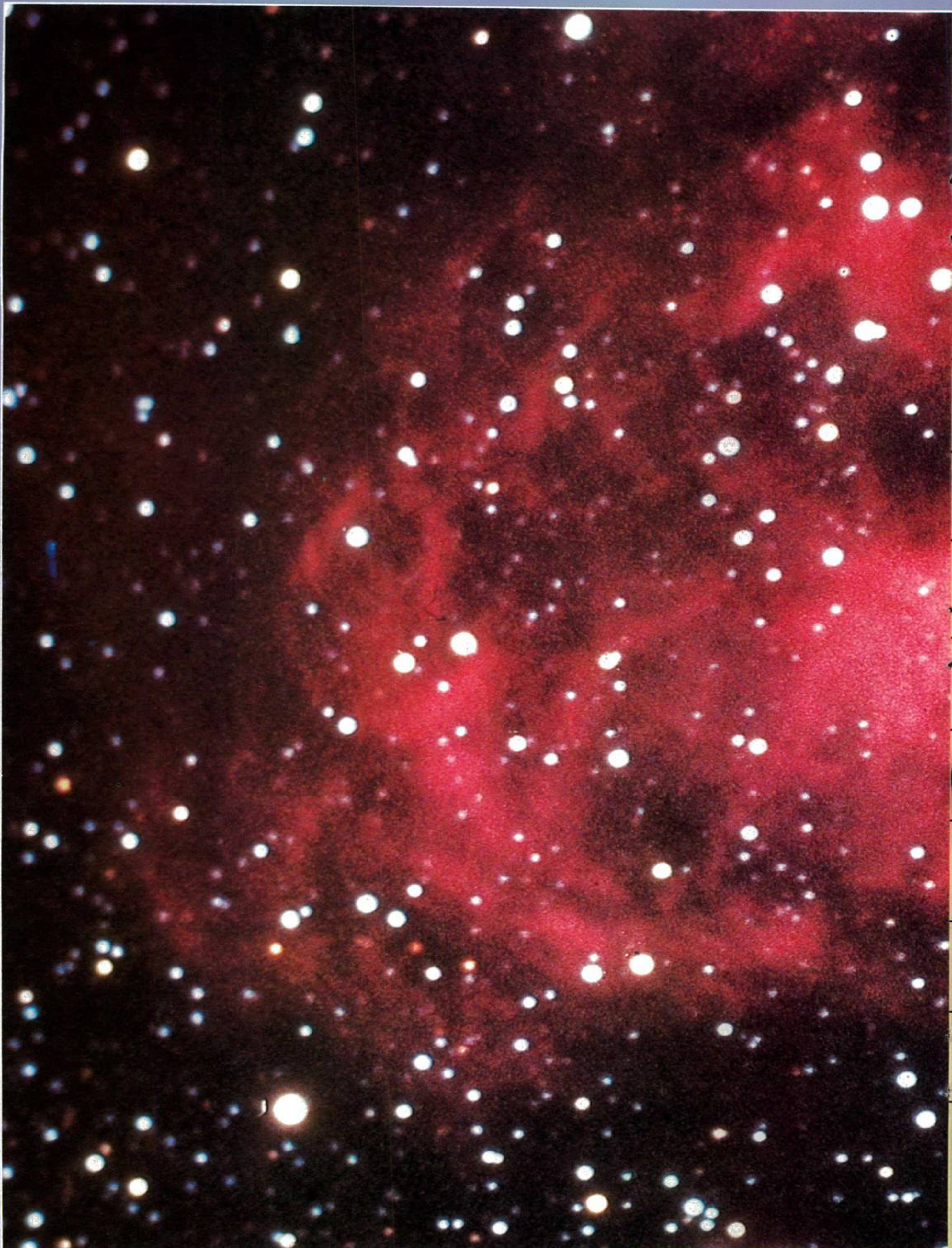
What's involved in it? Nothing more than using fine grain black and white film in the camera used for copying, *plus* the proper choice of filter. For example, imagine you're trying to bring out the subtle outer nebular loops of a bright red hydrogen nebulosity. Those fainter outer loops are, in all likelihood, red also. Make your copy through a red filter, then, to maximinze contrast between the nebula and the background sky.

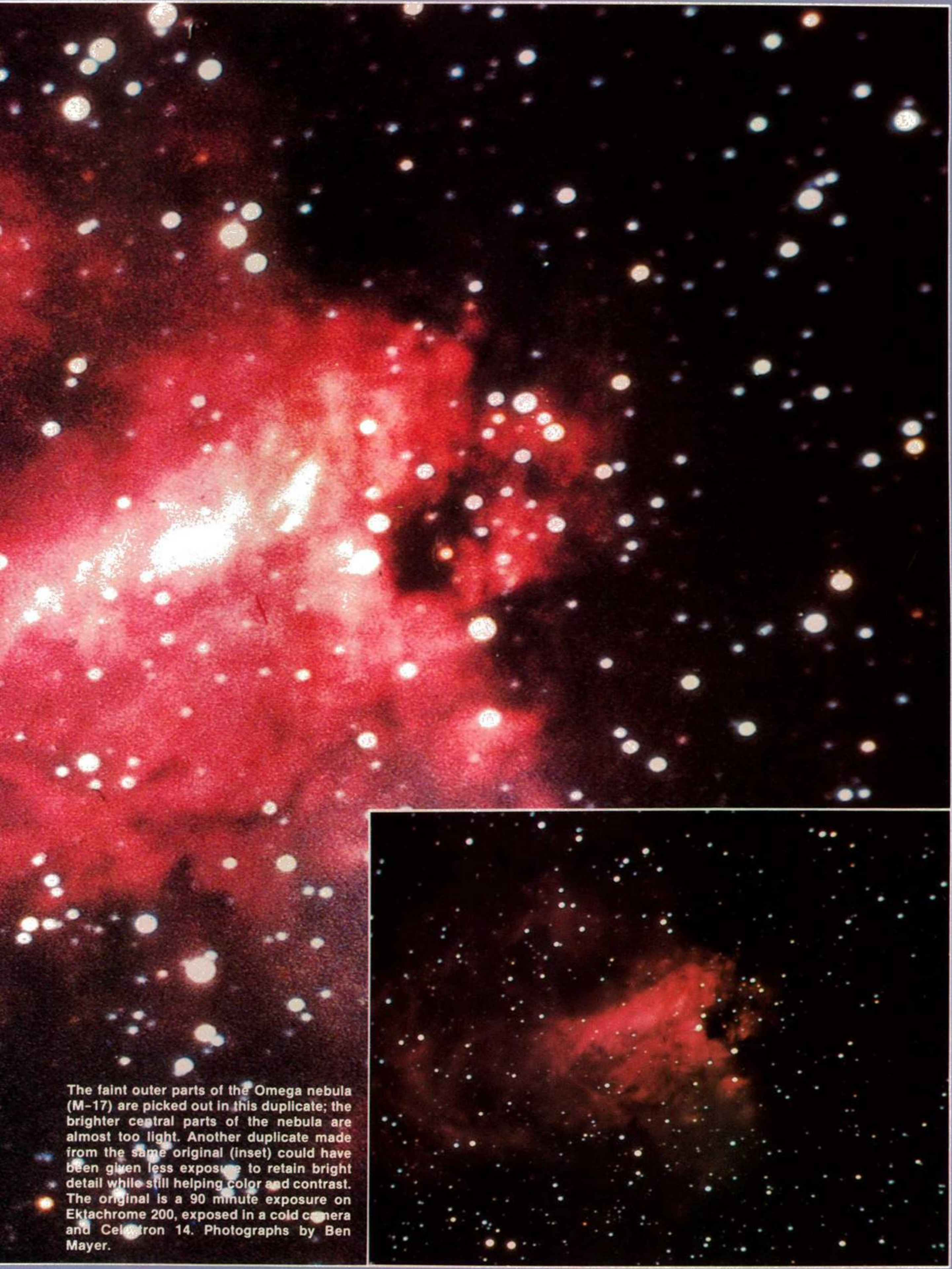
What if you're trying to bring out the outermost arms of a spiral galaxy? Since galaxies generally tend to be bluish, make your copy through a blue filter. Of course, you may also want to try making a copy with a red or yellow filter just to see what happens!

What films work best? Generally the slow panchromatic films are best; Pan-X, for example, works well. Even Tri-X can be used, if you don't intend to enlarge the image very much. You'll have to experiment to find the best exposure, but you'll usually find that if the exposure is right for the fainter outermost parts, the brighter inner regions are "burned out" and will appear completely white in a print. The examples on page 39 show what you can do with black and white rephotography.

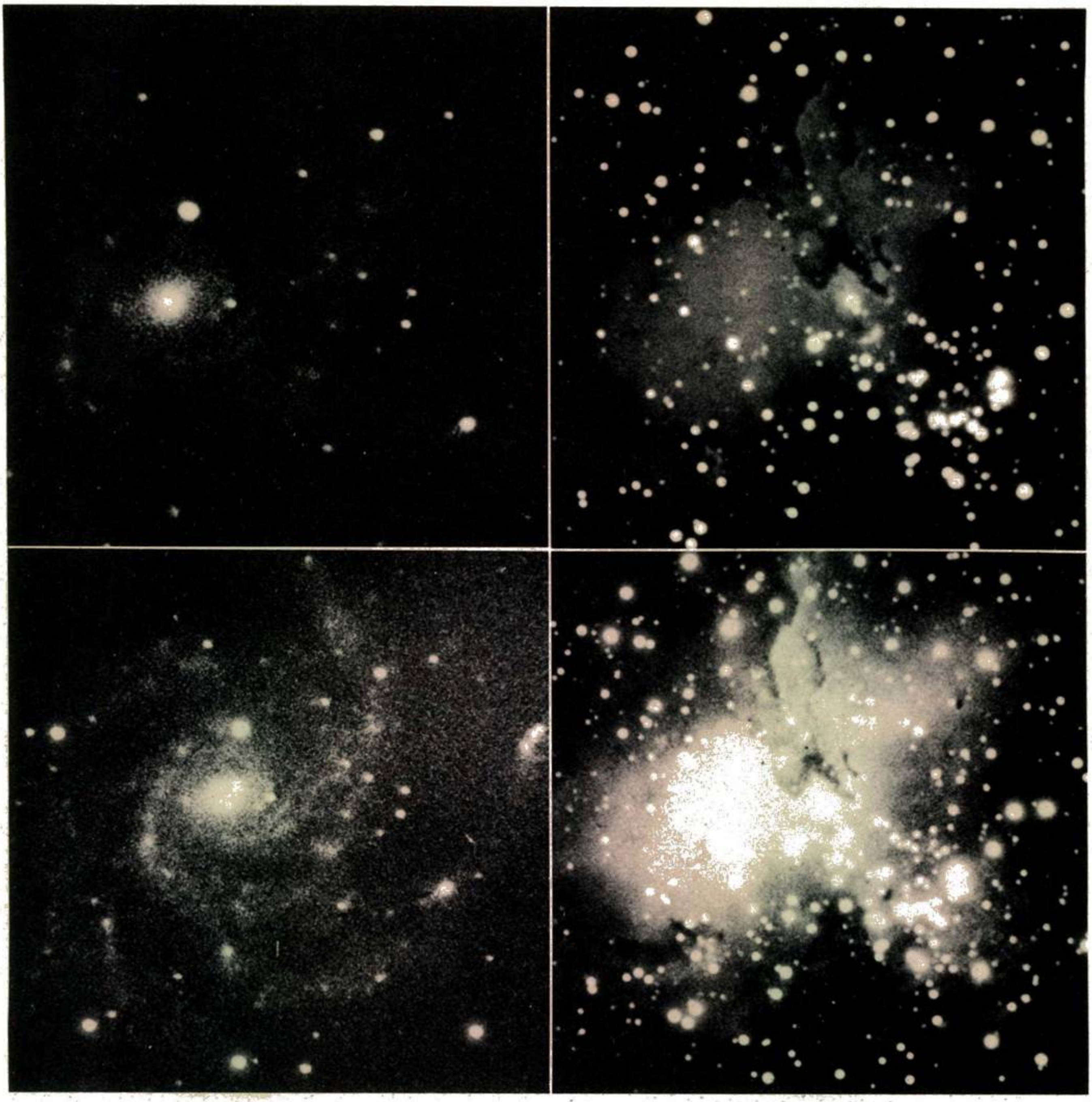
When is a duplicate not a duplicate? Through rephotography, this picture of the Trifid nebula is markedly enhanced in contrast, brilliance and visual impact. The original (inset) is an hourlong exposure on Ektachrome 200, using a cold camera and a Celestron 14. The rephotographed image — a copy on Kodachrome 25 — is not only enlarged, but also has a blacker background tone and more vivid coloration than the original. Photographs by Ben Mayer.







The faint outer parts of the Omega nebula (M-17) are picked out in this duplicate; the brighter central parts of the nebula are almost too light. Another duplicate made from the same original (inset) could have been given less exposure to retain bright detail while still helping color and contrast. The original is a 90 minute exposure on Ektachrome 200, exposed in a cold camera and Celestron 14. Photographs by Ben Mayer.



Opposite: The globular cluster M-13 (top) and the 900 year old supernova remnant called the Crab nebula (M-1) were recorded in 120 minute and 70 minute exposures respectively, and then rephotographed. Above: Black and white copies can preserve the appearance of an original (top left) — in this case the spiral galaxy M-101 — or through copying with a blue filter and exposing heavily (bottom left), accentuate features such as spiral arms. Hydrogen nebulae such as the Eagle (M-16) can be copied straight (top right), or enhanced by copying through a red filter (bottom right). Photographs by Ben Mayer.

advantage? Spend the extra time and attention so that the final result will be better than the original in beauty, contrast and composition!

As with all other photographic endeavors, it's important to keep exact records. If you want to duplicate a particular photo in exactly the same way at some future date, you can simply refer to your notebook and reproduce all the conditions precisely. Try using noon sunlight whenever possible (morning and evening sunlight tends to distort the color fidelity). Standardize the incident light as much as conditions allow and make a note concerning this crucial aspect. Write down the number of the extension tube used, the distance between the lens and the slide which is being copied, the exposure time, f/stop, and any other important variables. It's worth bracketing copy exposures by half-stops so you'll get maximum quality copies. Any time thereafter, you'll only need to look up the optimum exposure.

Experiment as you go along. Try a handheld flash attachment or find a color balanced light bulb in a camera store. Then you can re-create lighting conditions on future occasions, or make copies on rainy days or evenings.

One last word: Rephotograph only once. Re-rephotographing begins to degrade the images. But then again, you may wish to try this too; some of the results may intrigue you. Then, of course, there is re-re-rephotographing . . . .

Ben Mayer is best known for his PROBLICOM survey program (see ASTRONOMY, May 1978) and his prediscovery photographs of Nova Cygni 1975. And, as you can see from the pictures in this article, he is also an avid astrophotographer!

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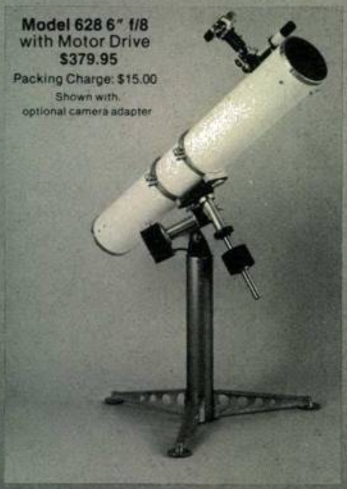

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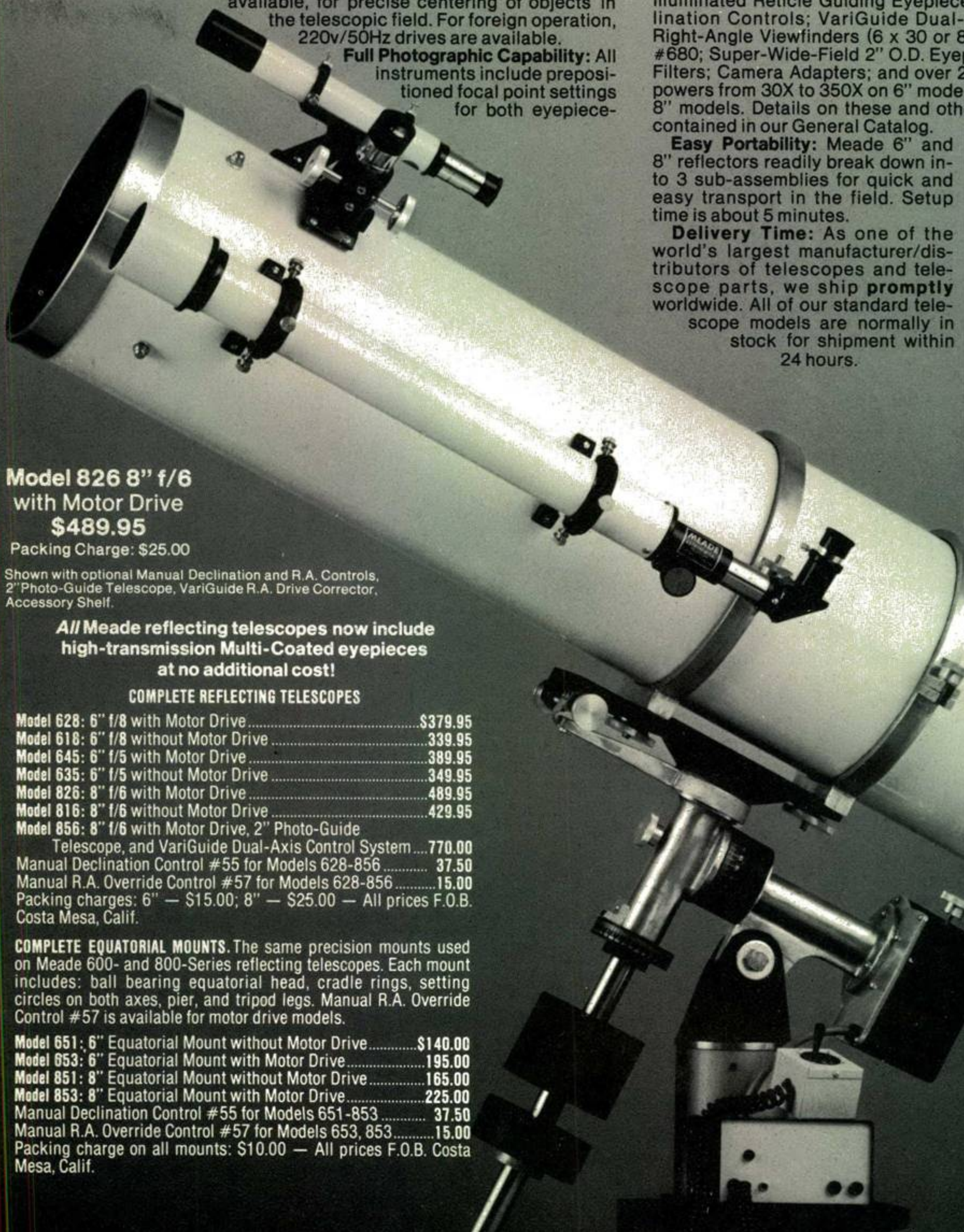

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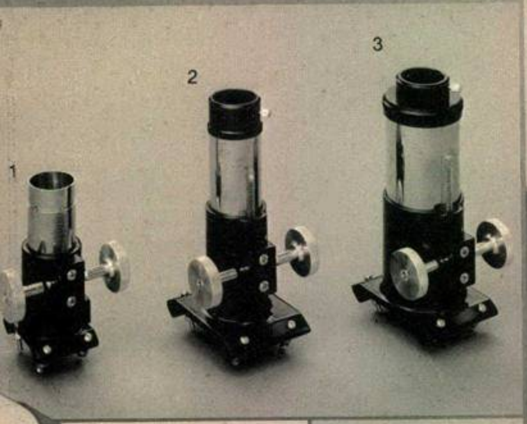

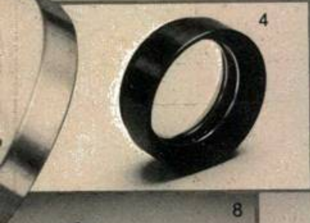

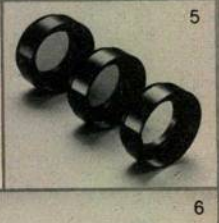

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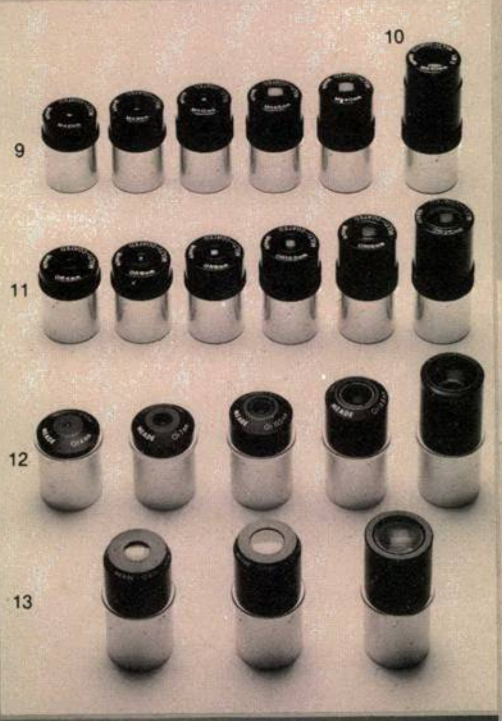

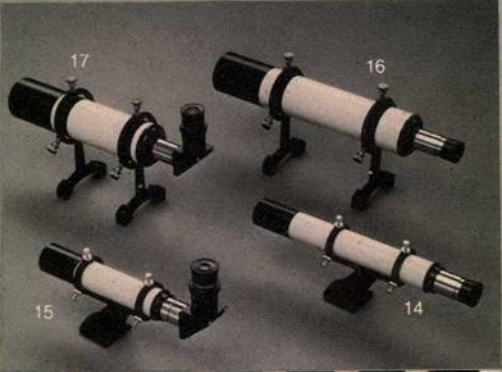

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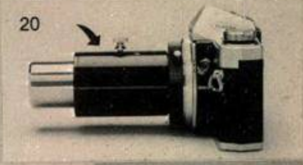

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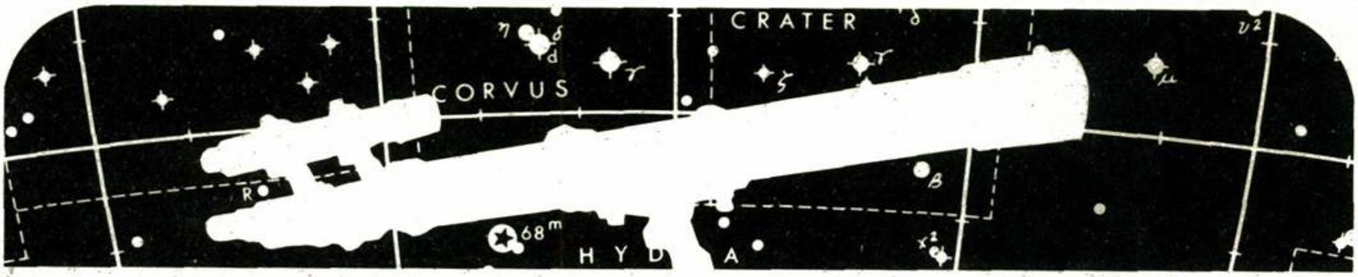


EQUIPMENT ATLAS

Eyepieces:

What You Get Is What You See!

by

Dewey Schwartzenburg

All telescopes, from the smallest homemade instruments to the largest observatory giants, are a combination of two systems: optical and mechanical. The mechanical system is quite literally the nuts-and-bolts of a telescope — the supports, mounting, drive, controls and so forth.

The optical system, of course, is the business end of a telescope — the part which does the job of collecting, focusing and magnifying light. It consists of two main parts, the objective and the eyepiece. The function of the objective in any telescope design is to gather light and focus it to a point. Whether the objective is a mirror or a lens, the amount of light gathered is determined by the size of the objective. Accuracy of focusing is a function of the optical design of the objective — the precise curves given to the surfaces of the lens or mirror.

But after all this has been done, we have only what is called a focal plane image — a much brighter and somewhat magnified image of whatever the telescope is pointing at. It is the job of the *eyepiece* to render that image viewable.

Basically, what an eyepiece does is magnify the focal plane image formed by the objective. It's actually a microscope, used to examine the image closely in detail!

Eyepieces are the most important pieces of optical equipment after the objective itself, but many beginning astronomy enthusiasts find them mysterious. What's the best kind — Huygens, orthoscopic, Kellner or Ramsden? How are they different? How many eyepieces should you have, and what kinds?

Before we answer these questions, let's look at eyepieces in general. An eyepiece is a precision optical instrument and is as important to the performance of your telescope as the objective lens itself. No matter how good the main lens is, if it's combined with the wrong kind of eyepiece, or an eyepiece of inferior quality, or one used improperly, the performance of your telescope will be lessened.

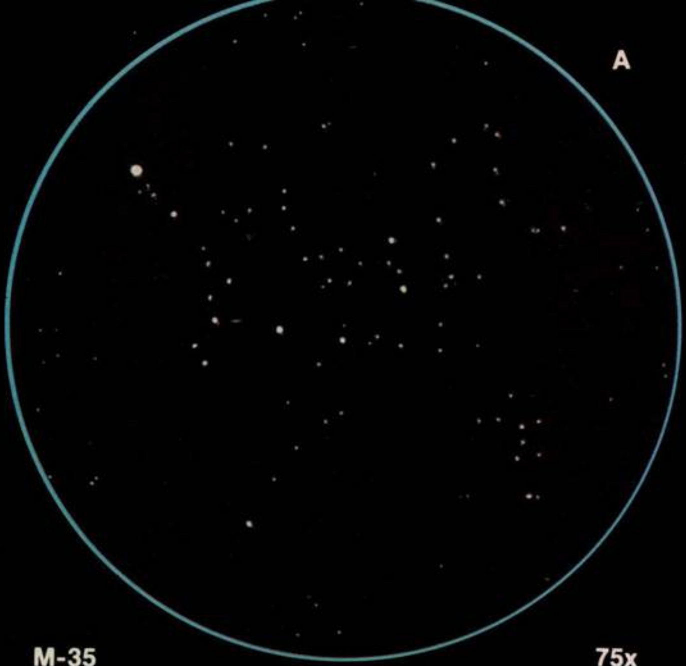
Eyepieces are subject to the same flaws as an objective lens, and a perfect one would be one which is free from all optical distortions. However, this does not mean that you must buy only the best, most expensive eyepieces available, for in many cases the distortions to which a particular eyepiece is subject may not impair its performance significantly. Thus, it would be foolish to spend money for a "better" eyepiece when a cheaper one will do just as good a job — especially these days when eyepiece prices seem bound for the moon!

One important consideration is magnification. Although it's possible to have more eyepieces than you really need, one is never enough. The main thing is to have a set of eyepieces which will provide a range of magnifications from low to high. Some celestial objects, such as open clusters, must be viewed at a low magnification to get all the object in the field of view; others, especially planets, require high magnification to render detail visible.

But your eyepieces don't come labeled with a particular power. Instead, they are catagorized by their focal length. This is because the same eyepiece will provide different magnifications with objectives of

Different celestial objects call for different powers; it's important to use the correct eyepiece for the object you are viewing. Shown on the facing page are a number of typical views as they would be seen through a small (three to four inch) telescope at the proper magnitcation. *(A)* The lowest power possible should be used for extended objects like open clusters. *(B)* 100x is a good choice for observing lunar detail, though higher powers may be used to zero in on a particular feature. *(C)* A moderate magnification such as 120x is appropriate for viewing such objects as gaseous nebulae. Somewhat higher powers may be desirable for the more compact planetary nebulae. *(D)* Planetary observation calls for still higher magnifications. Here, 150x enables the observer to examine cloud belts on Jupiter. The Great Red Spot is clearly seen, and watching transits and occultations of the satellites will be easy. *(E)* In order to observe detail on the tiny image of Mars, you'll need something in the area of a 200x magnification. In this view, dusky markings and the north polar cap are visible. *(F)* Rarely, you may want to push the magnification beyond the theoretical limit for your telescope (around 50x for each inch of aperture). Here a very high magnification of 400x is used to clearly separate the components of a binary star. The diffraction disks which appear at high magnifications show that this optical system is nearly perfect. Artwork by Victor Costanzo.

A



M-35

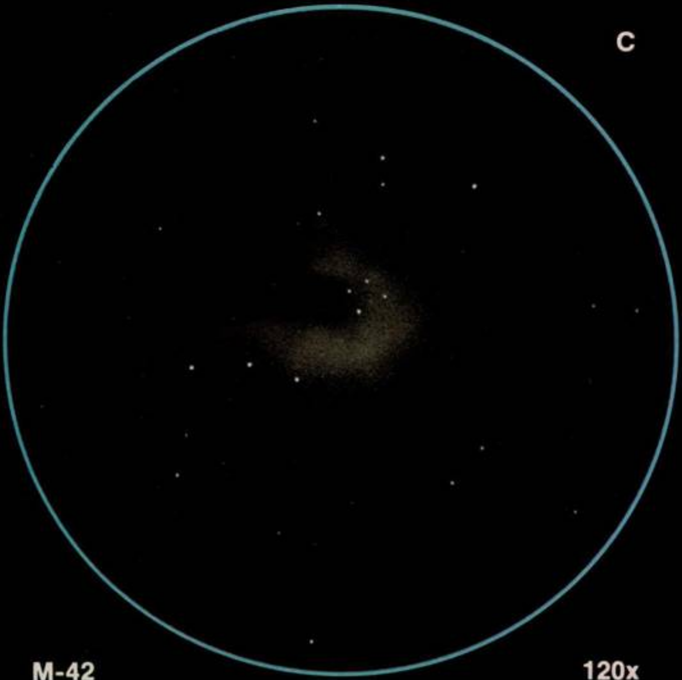
75x

B

100x

MOON

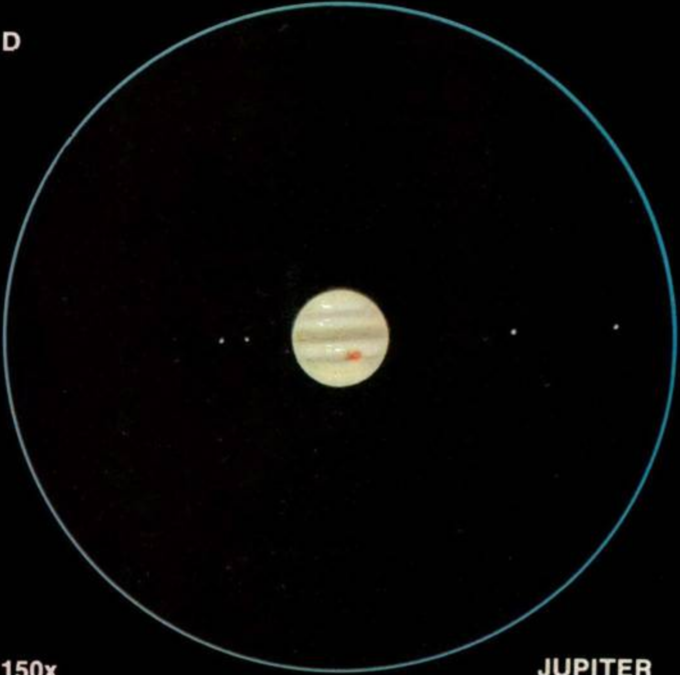
C



M-42

120x

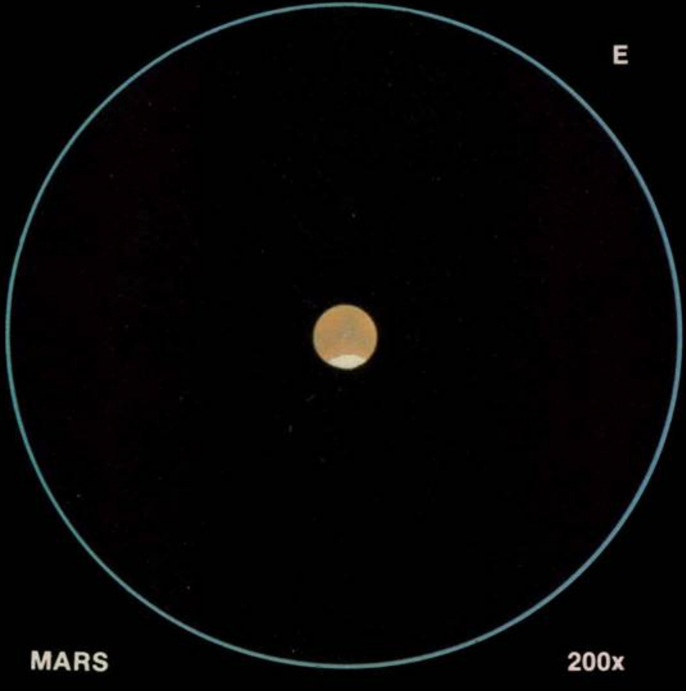
D



150x

JUPITER

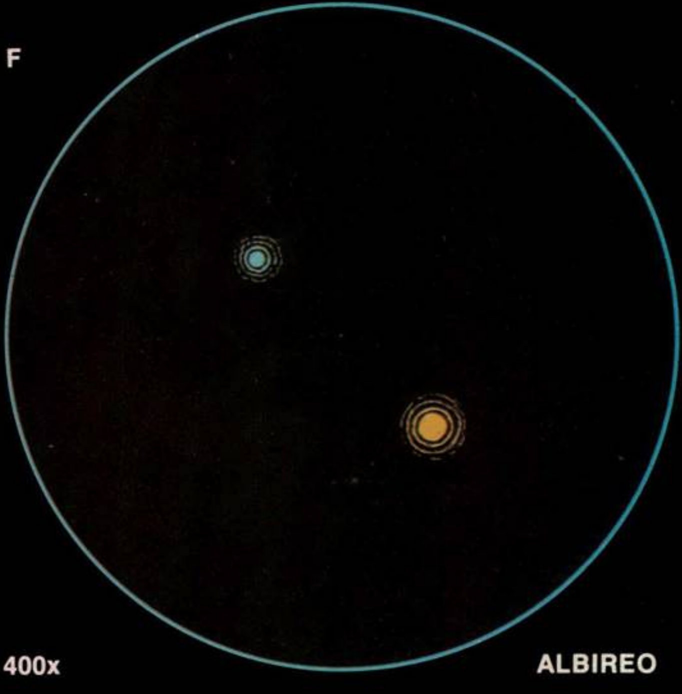
E



MARS

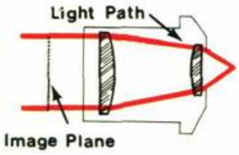
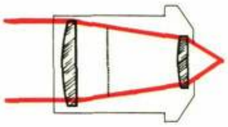
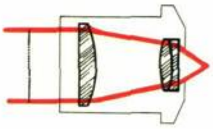
200x

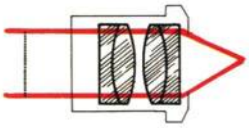
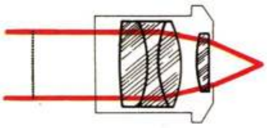
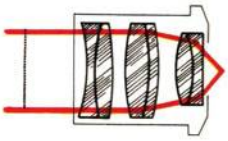
F



400x

ALBIREO

Eyepiece	**Ramsden**	**Huygenian**	**Kellner (Achromatic Ramsden)**
Optical Design			
Focal Length	12 — 30mm	18 — 40mm	7 — 60mm
Apparent Field of View	narrow, especially under 12mm	fair	fair
Eye Relief	short	short	good
Curvature of Field	less than Huygenian but still noticeable	bad	little
Distortion	less than Huygenian but still noticeable	a great deal unless f/ratio is very long	very little
Ghost Images	noticeable	less than any other two-lens type	very subject to ghosts; especially noticeable on bright images
Chromatic Aberration	less than Huygenian, but still bad, especially with refractors	a great deal unless f/ratio is very long	corrected Ramsden design, works very well
Spherical Aberration	less than Huygenian	a great deal unless f/ratio is very long	very little
Cost	low	low	moderate
General Comments	best suited for small reflectors of f/8 or greater	works well with refractors of f/15 or greater	a good buy for most telescope users, provided ghost images won't be a problem

Symmetrical	Orthoscopic	Erfle	Eyepiece
			Optical Design
18 — 40mm	4 — 25mm	16 — 40mm	Focal Length
wide	moderate	very wide	Apparent Field of View
excellent	good	large amount; good for eyeglass wearers	Eye Relief
very little	virtually none	very little	Curvature of Field
very little	virtually none	very little, except sometimes at edge of field	Distortion
some ghost problems	negligible	a common defect	Ghost Images
adequate correction	virtually none	very little	Chromatic Aberration
adequate correction	virtually none	very little	Spherical Aberration
moderate	high	high	Cost
a fine eyepiece for low powers that can be used in almost any telescope	best for high power observing on any telescope; excellent for planetary observations	best for low power, wide field observing; excellent for richest-field telescopes; some light loss	General Comments

different focal lengths. The magnification a particular eyepiece will provide with your telescope is easy to calculate. All you need to know is the focal length of your objective lens and that of the eyepiece — marked in millimeters directly on the eyepiece. You'll have to calculate the focal length of your objective lens in millimeters if you don't already know it. Then divide the objective focal length by that of the eyepiece, and the result is the magnification. For example, an eyepiece with a focal length of 25mm will give a magnification of 60x with an objective of focal length 1,500mm, and 80x with one of 2,000mm focal length (1,500/25 = 60; 2,000/25 = 80).

How many eyepieces should you have? A good number to start with is three — one to provide as low a magnification as possible, one for high magnification and one intermediate. There's a practical limit to the magnification for a particular objective lens. A good general rule is to go no higher than 50x for each inch of aperture. Thus, if you have a four inch reflector, your limit is about 200x, and a six inch will allow you to go to 300x. In any case, you'll soon discover that you are using your low power eyepieces far more than the highest, for there are very few objects for which high magnification is really desirable. You'll probably find you're more interested in filling in the gaps between your lower powers than in getting more high power eyepieces!

The accompanying table lists the main types of eyepieces widely available today, although some exciting new designs have recently been introduced. You might want to try some of these newer eyepieces, such as the Edmund RKE. Just because a design is not listed doesn't mean it isn't recommended; the table only lists the classic types in common use.

The table also provides the following information about each type:

Focal length: The optical design of each type of eyepiece is especially suited for a certain range of focal lengths, as listed. Often eyepieces of shorter and longer focal lengths are available, but flaws and distortions will be more prevalent in these cases. All eyepieces should fall somewhere between 4 and 40 millimeters.

Apparent field of view: There are two fields of view associated with any eyepiece — an apparent field of view and the true field of view. The true field of view is the actual area on the sky visible with the eyepiece, measured by its diameter in minutes and seconds of arc. This will depend not only on the eyepiece but also on the optical characteristics of the objective lens. On the other hand, the apparent field of view is the angular diameter of the field seen through the eyepiece — always much larger than the true field of view! (The true field of view can be calculated by dividing the apparent field of view by the system's total magnification.) A wide field of view, while dramatic for observing the richness of an open cluster, for example, is not always essential.

Eye relief: This refers to the distance between the eye lens of the eyepiece and your eye. It should be as large as possible, especially if you wear glasses, or else you may not be able to get close enough to the eyepiece to see the image clearly.

Curvature of field: A good eyepiece should provide a flat field of view. That is, the image should be in focus from the center of the image right out to the edge of the field. Some eyepieces produce a curved field, where it is impossible to bring the entire image into focus at once.

Distortion: Some eyepieces are subject to a condition in which the magnification actually varies in different parts of the field. This will distort the image so that straight lines will appear curved. Distortion will result if magnification either increases or decreases when moving out from the center to the edge of the field. An eyepiece free from distortion will provide the same magnification from the center right out to the edge.

Ghost images: Internal reflections in the eyepiece can result in ghost images. These can be especially distracting when observing bright objects. The nebula or comet you think you are observing may be only the ghost image of a nearby star!

Chromatic aberration: Some eyepieces may have slightly different focal lengths for light of different wavelengths, resulting in colored fringes around images. When blue is in focus, red light is blurred and out of focus around the image, and if the red light is brought into focus, blue will be out.

Spherical aberration: This results when all the light rays entering the eyepiece fail to come to the same focal point. It is impossible to focus an eyepiece with spherical aberration at all — even for a particular wavelength — and overall loss of sharpness is the result.

Cost: It seems eyepieces have been increasing in cost faster than anything else these days, so the table provides only relative estimates of low, moderate and high. In general, the more complex the eyepiece's optical system, the more expensive it will be. But beware of "bargains" — a bargain orthoscopic eyepiece may indeed have the orthoscopic optical arrangement of lenses, but if those lenses aren't precisely figured from high quality glass, you'd be better off buying a good Ramsden.

In fact, the comments in the table all refer to good eyepieces of each type. Orthoscopic eyepieces are noted for being free from optical distortions, but this ceases to be true if it is poorly made of inferior materials.

Most of the eyepieces listed are two lens systems, composed of a field lens and an eye lens. The purpose of the field lens is to increase the field of view, while the eye lens magnifies the image formed by the field lens. The Huygenian and the Ramsden are both simple two lens eyepieces; the only difference in design is that in the Ramsden, the field lens is reversed. This places the image before the field lens instead of between the two lenses. In a Ramsden, a trade-off must be made between chromatic aberration and eye relief — the greater the eye relief, the worse the chromatic aberration will be. The Kellner design, also called an achromatic Ramsden, solves this problem by replacing the simple eye lens with a cemented doublet to correct chromatic aberration. Unfortunately this results in a lot of internal reflection and ghost images.

The symmetrical eyepiece, sometimes known as a Plössl, uses cemented doublets for both the field and eye lens. Ghost images are reduced while a wide, flat field with excellent eye relief is provided. The orthoscopic design also uses a total of four lenses cemented into two compounds, but the field lens is a triplet while the eye lens remains simple as in the Huygenian and Ramsden. It is one of the most successful designs. Unfortunately, it is also one of the most expensive!

In addition to the two lens system, eyepieces may be composed of a single element (either simple or a cemented doublet or triplet). These are relatively rare, although some of the cemented triplet designs (such as the Zeiss) are excellent performers.

In the other direction, you may go to a three lens system, sometimes called a compound eyepiece. Because of the number of lenses involved, compounds tend to be fairly expensive, but their fine performance makes up for their high price. One problem, though, is loss of light due to all those layers of glass, so compounds are not suitable for dim objects or detailed planetary study at high magnifications. The only example given in the table is the Erfle, famed as the "Cinerama" of eyepieces for its exceptionally wide field of view.

The eyepiece is an important factor in astronomical observations. Too often poor performance of a telescope is blamed on the objective lens, when it is inferior or unsuitable eyepieces which are at fault. It is worth the time to examine the possibilities carefully before investing in a set of eyepieces for your telescope!

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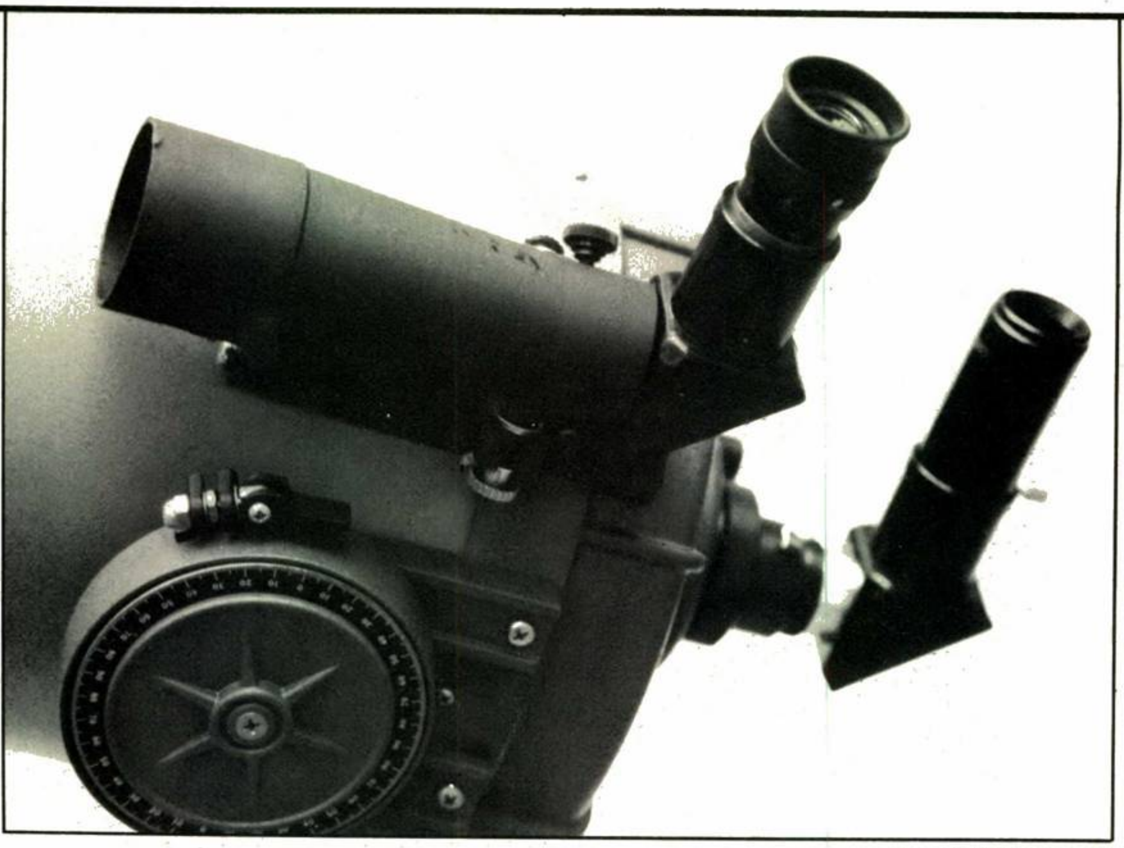

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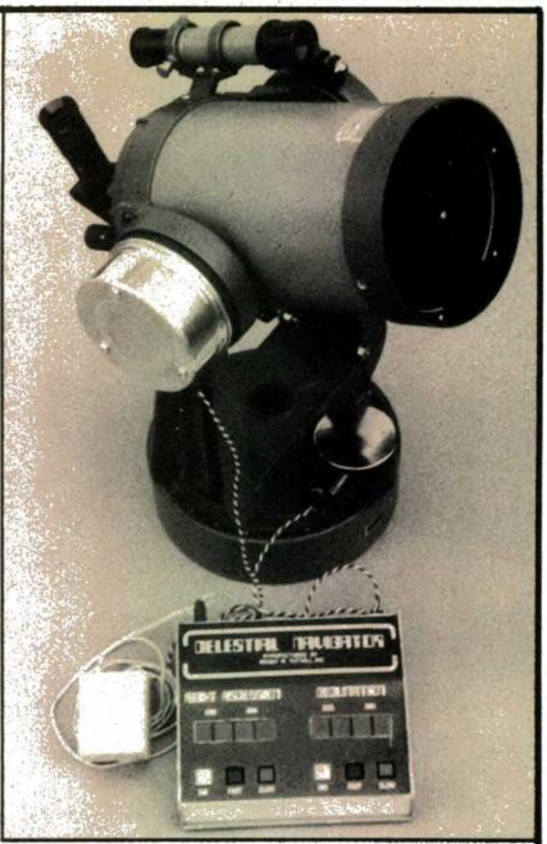

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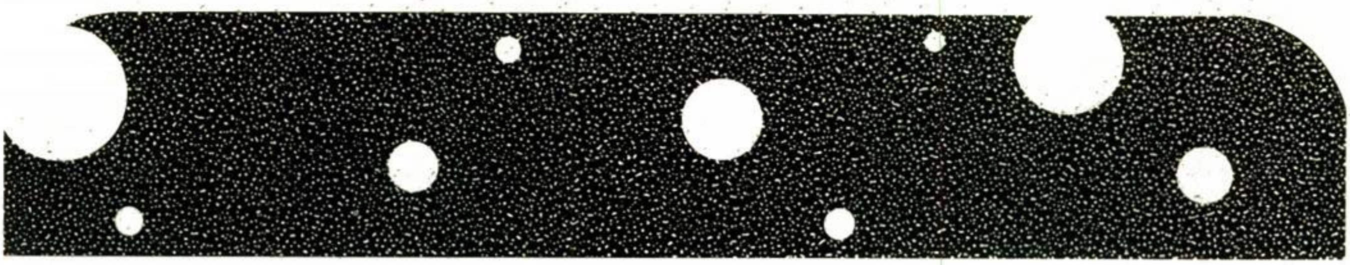


STELLAR FRONTIERS

A New Revolution in Solar Physics

by

David H. Clark and F. Richard Stephenson

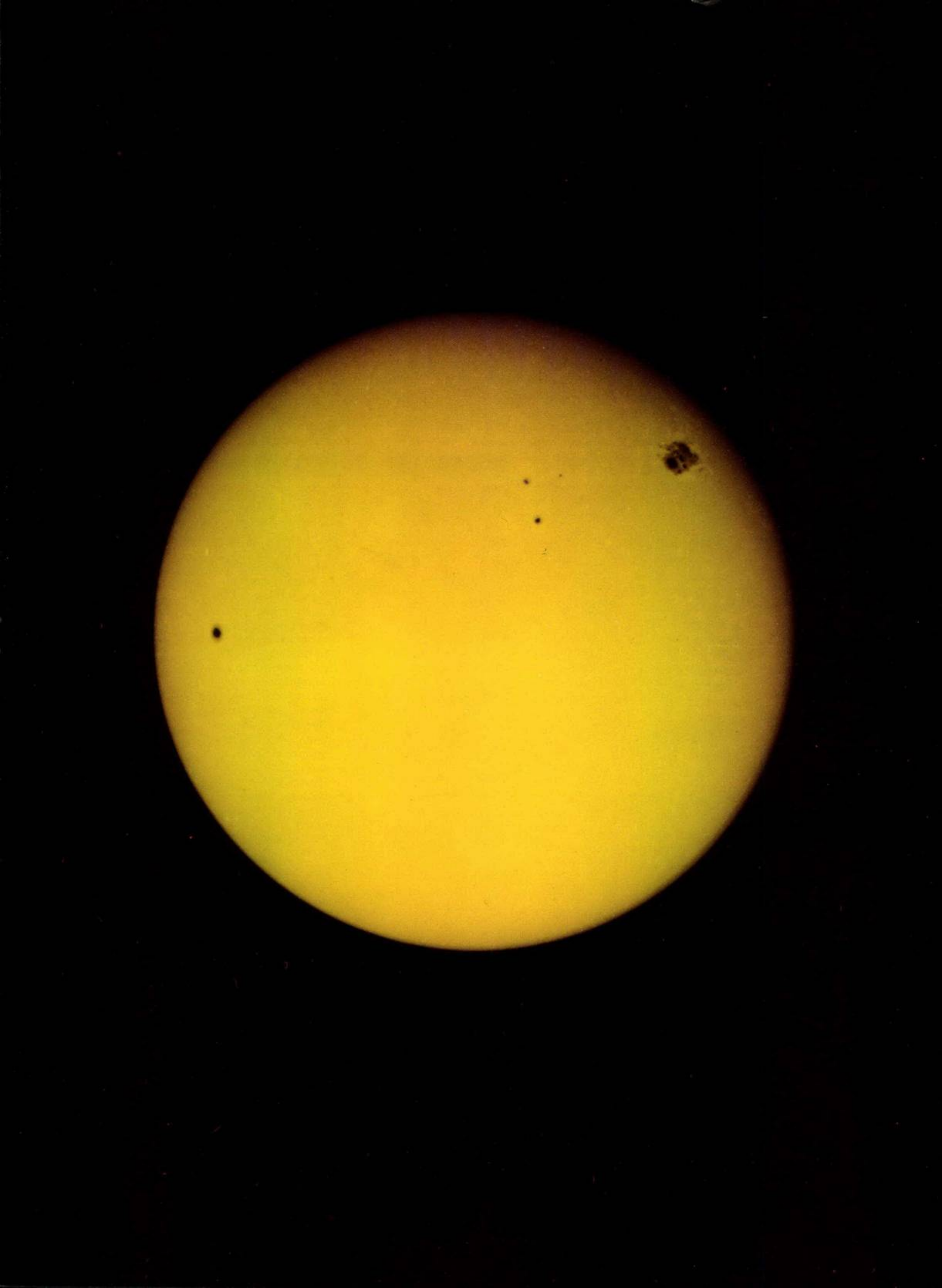
The modern understanding of the sun has allowed for some change in what was once thought an unchangeable body. Such indicators of solar variability as sunspots, the extended solar magnetic field, flares, aurorae and other phenomena, have been extensively studied in modern times. Yet even in such indicators of inconstancy, a certain measure of predictability had been established. Solar activity has been believed to follow a "quasiregular" 11 year cycle, most dramatically evidenced in post-telescopic plots of the annual means of observed sunspots.

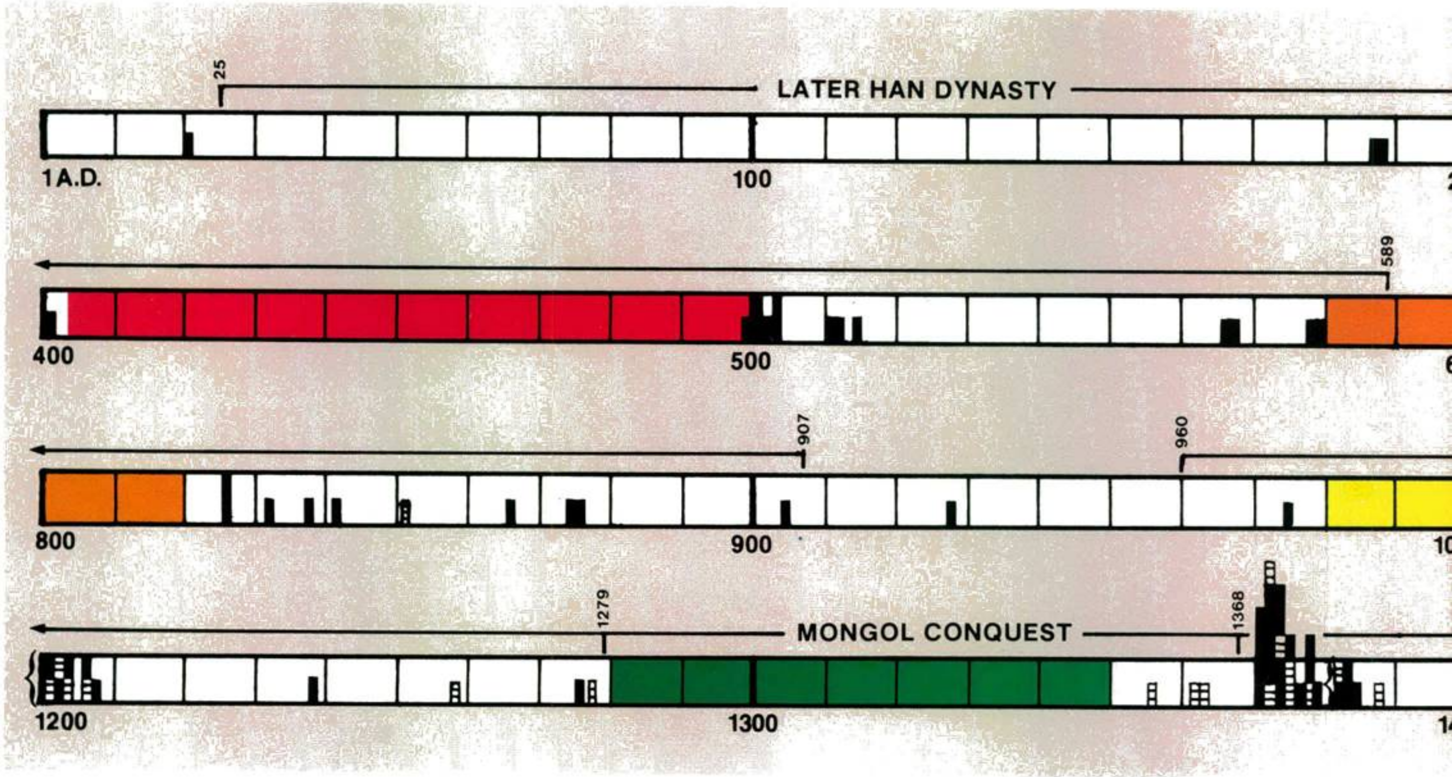
The past few years has seen the start of a new revolution in scientific belief, in which the "regularity" of solar behavior is now being openly questioned. John Eddy of the High Altitude Observatory in Boulder, Col., has recently redrawn attention to an apparent protracted minimum in sunspot activity in the late 17th century. This period of sunspot absence is now known as the *Maunder minimum*, in recognition of Walter Maunder's persistent, but unsuccessful, efforts over a 30 year period (beginning in 1890) to convince his contemporaries of the significance of the evidence of solar *in*activity. A similar major excursion, which evidence now suggests occurred during the 15th and 16th centuries, is called the *Spörer minimum* in honor of another early investigator.

Eddy has strengthened the reality of claims that the sunspot cycle essentially vanished between 1645 and 1715 from a re-analysis of the contemporary literature detailing auroral records, sunspot counts, observations of the sun at total eclipse, plus indirect evidence from atmospheric isotopes and paleo-climatic data. If the sun could display one such major departure from "regularity", the question arises as to whether such major excursions have occurred before — whether they may in fact be relatively frequent — or even whether the sunspot cycle of modern times, which has formed a cornerstone of solar physics, may be no more than a transient feature of the sun's behavior. Adoption of any such ideas would indeed represent a revolution in astronomical thought.

It's now apparent that a few pretelescopic sunspot records are contained in histories from the Occident, even if their exact nature was not appreciated at the time. Bernard Goldstein has shown that certain dark features on the sun, recorded in the Middle East and attributed to Mercury and Venus, did not correspond to actual transits, and were therefore presumably sunspots. The two most specific allusions to sunspots from the Occident both originate from 14th century Russia, and both sightings were at times of forest fires. For instance, in 1371: "During this year there was a sign in the sun. There were dark spots on the

The photo on the facing page shows several sunspots. The large group at upper right is within the limit of resolution of the naked eye, and would be easily visible without artificial aid if the glare of the sun's disk were reduced by atmospheric haze or dust. It is now known that such large markings were occasionally observed long before the invention of the telescope! Photograph by James K. Rouse.





The time chart above shows ancient observations of sunspots in the Far East. Chinese records are represented by solid bars, and those from Korea or Japan by open cross-hatched bars. Each unit bar represents a single sighting, and the height represents the number of sightings in a particular year. It is clear that in most years, no more than one sighting was made. Sometimes the same sunspot activity was recorded (after 1150) in both China and Korea; such dual sightings are bracketed. Dynastic periods are marked above the time line, including the period of the Mongol conquest [when China was ruled by the foreign Yuan dynasty, founded by the famed Kublai Khan (1216-1294)]. On the basis of modern solar activity, you might expect more sightings than indicated above, even though no good evidence exists that a regular watch was kept for sunspots throughout Oriental history. However, during almost the whole of Chinese history since Han times, the acknowledged systematic and careful approach to observational astronomy and its complete documentation, and the belief that celestial phenomena were precursors of terrestrial events, make it unlikely that sunspots were omitted from regular patrol. The possibility that solar activity on the whole was significantly less during this 1,600 year period must be seriously considered. We may now be undergoing a time of unusual solar upheaval!

sun, as if nails were driven into it, and the murkiness was so great that it was impossible to see anything for more than seven feet.... Wood and forests were burning and the dry marshes began to burn." This example emphasizes the need for diminished solar brightness due to atmospheric haze, duststorms, severe atmospheric absorption (say near sunrise or sunset), etc., to render sunspots visible to the naked eye.

The abundance of historical sunspot records from China over the last 2,000 years must be attributed, at least in part, to the regular occurrence of atmospheric conditions suitable for the detection of sunspots. The geology of China renders it susceptible to duststorms, particularly off the Gobi and Tarim plains. In addition, there is a high incidence of atmospheric haze associated with a continental climate. The eminent historian of Chinese science, Joseph Needham, has suggested that the sun might have been viewed through pieces of semitransparent jade, mica or smoky rock crystal, although there seems to be no confirmation of this in the available contemporary literature. Nor is there any evidence that the Chinese realized the sun could be "imaged" with a pinhole device.

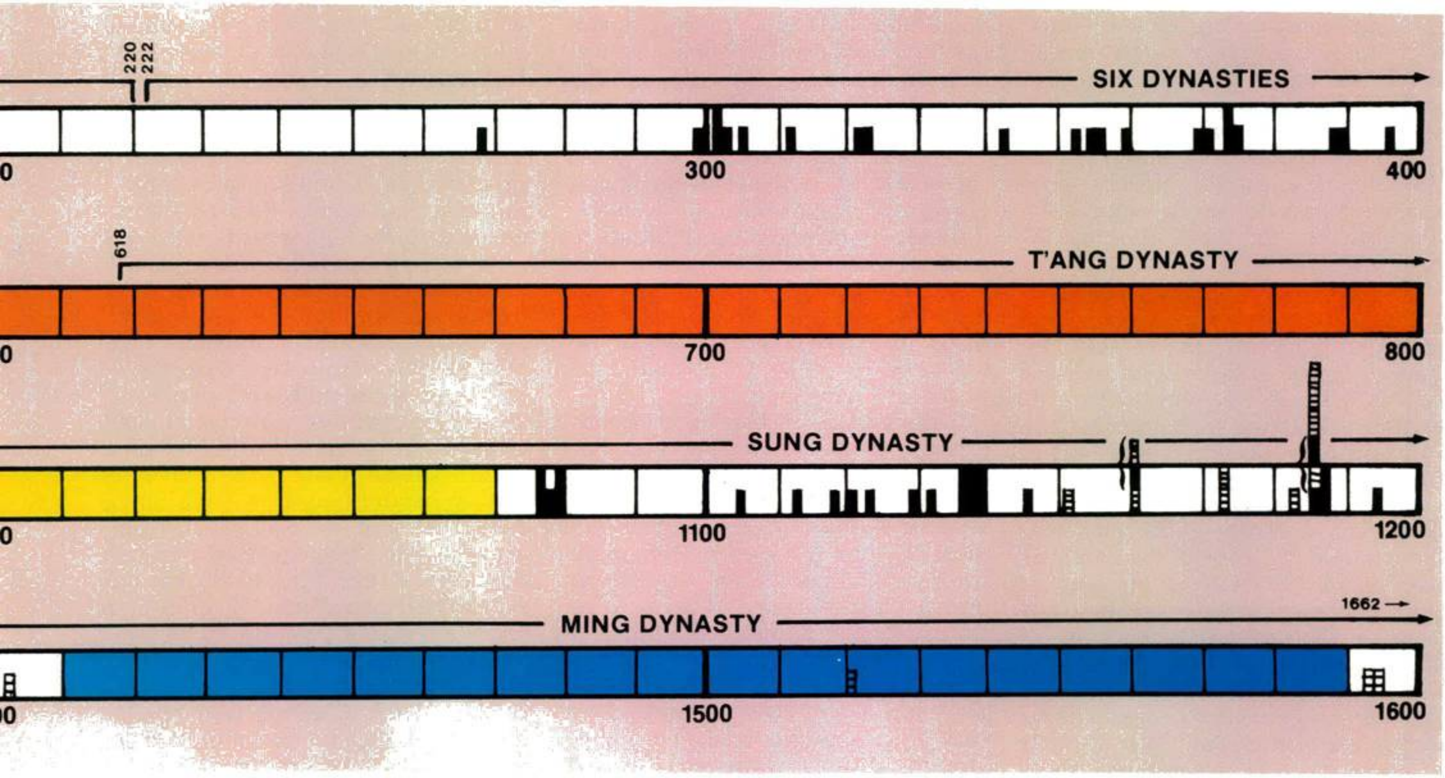
Additional reasons for the relatively large number of sunspot records from the Orient must include the open acceptance of variability in the heavens, the long tradition of astronomical investigation based on the belief in celestial influence on terrestrial events, and the compendious documentation of astronomical observations.

The first definite recording of a sunspot in the Orient dates from 28 B.C. (earlier allusions are not conclusive). Early enlightened opinion discounted solar mythology; for example, we read in the history of the Han dynasty: "The scholars say that the sun has a three legged crow inside. But the sun is just fire in the sky, and is no different from fire on Earth. If terrestrial fire does not generate anything within it, how can the celestial fire produce a crow?"

The historical Oriental sunspot records are especially picturesque. For example, we read in the record for 352-353 A.D.: "According to observations made by Chang Ch'ung at Liang-chou, the sun was a dazzling red, like fire. Within it there was a three legged crow. It's shape was seen sharp and clear. After five days it ceased."

The rich astronomical heritage of China, and the veritable gold mine of useful naked eye observational data from a full two millennia, have their roots in political astrology. The emperor was regarded as the "Son of Heaven", so that celestial phenomena, no matter how trivial, were of great concern to the throne. In order to detect celestial admonitions, and take counteraction promptly, court astronomers were appointed by the ruler to maintain an assiduous watch of the sky.

We have searched the dynastic histories, encyclopedias, etc. for all possible references to sunspots. There have been several such searches made previously, most notably by Kanda Shigeru in Japan in 1953, and "The Ancient Sunspot Records Research Group" of Yunnan Observatory in 1976. Our search revealed just a single new sunspot record not found in earlier searches, although our rigorous interpretation of the data has



meant the exclusion of several records previously cited, but which we believe to be spurious. A total of 106 pretelescopic reports from China, 32 from Korea, and just one from Japan were included.

The most striking feature of the results is the relative paucity of data — the historical sunspot records appear to be highly fragmentary and sporadic. At no period were more than 30 sightings recorded per century. A regular search might have been expected to have revealed a somewhat greater number if sunspot activity was at present day levels.

The paucity of Oriental data must surely argue against Needham's suggestion that semitransparent materials were used from early times to aid solar viewing. Maunder, writing early in this century, reported that at the Greenwich Royal Observatory, a controlled survey indicated that sunspots could be observed through a suitable filter with the unaided eye on about 250 days per year. Yet without a filter, say at sunset, they are rarely seen from Britain. The authors have surveyed the setting sun on over 100 occasions during the past 24 months, but have only once unambiguously identified a naked eye sunspot. While it's true that this period was near a sunspot minimum, so was the period of Maunder's controlled experiment. During the 19th century, naked eye sunspot sightings seem to have been a sufficiently rare occurrence to warrant a report in the Notes of the Royal Astronomical Society. Perhaps, after all, even with the more favorable conditions of China, the paucity of historical naked eye sunspot sightings is not totally unexpected.

It is only the largest of individual spots and unresolved large sunspot groups that can be detected easily with the naked eye. Thus, since such sunspot configurations are now recognized as being most common near the maximum of the sunspot cycle, historical naked eye sightings might be expected to delineate times of enhanced activity. Eddy has warned against such simple interpretation, correctly emphasizing that occasional large spots might still appear near the sunspot minimum, and arguing that the paucity of historical records makes them rather poor indicators of variability on short time scales and any search for periodicity futile. He wrote, "It seems highly unlikely that the sun would produce a single burst of activity, like the eruption of Old Faithful, at precisely the same phase of each cycle and remain relatively dormant for the 11 years between." Despite these reservations, historical sunspot records plus other indicators of solar variability (for example, aurorae and tree ring data) have been used with apparent success to recognize short-term (approximately 11 year) cyclic solar activity behavior for at least selected periods during the pretelescopic era. It has not, however, been our objective to search for short-term variability in the historical data; rather, we have been looking for gross long-term differences in solar behavior.

The time chart shows five long-term gaps (of about 100 to 200 years) in the historical Oriental sunspot records after the early interest in the 4th century. These are distinguished by color in the figure. Could any of these represent major excursions in solar activity similar to the Maunder minimum? These are:

1) from about 400 to 500 A.D. (red gap);
2) from about 580 to 820 A.D. (orange gap);
3) from about 980 to 1060 A.D. (yellow gap);
4) from about 1280 to 1350 A.D. (green gap), and
5) from about 1400 to 1600 A.D. (blue gap).

For both China and Korea, political and social pressures clearly influenced the recording of phenomena or astrological interest, and this must include sunspots. The emperor, supposedly governing with a mandate from "Heaven", could rule only as long as he governed wisely and justly. A departure from the way of virtue was expected to be indicated by the occurrence of certain celestial phenomena. If "warnings from Heaven" seemed not to be required by the high officials of court who dictated what should be recorded by the historiographers, celestial events might not be memorialized. An abundance of records of astrological significance, with their accompanying admonitions and prognostications, are often found to precede the overthrow of a dynasty; indeed, Needham has suggested that there was a stylized pattern of what was supposed to take place (by way of celestial portents) at the catastrophic close of a dynasty. With these various reservations in mind, we must consider whether periods of scarcity of historical sunspot records might result from protracted minima sunspot activity (similar to the Maunder minimum), merely from lack of interest, deliberate suppression of evidence, or from the loss of historical data.

The continuity of sunspot records in the astronomical histories for particular dynasties can be checked by comparing the frequency of sunspot records with the frequency of records of other celestial phenomena. The number of solar eclipse records (important for calendrical purposes) may give a somewhat false indication of the completeness of astronomical observations, since a significant fraction of the reports (at least a quarter) were predicted but not observed. The essential continuity of the data is, however, obvious. Nevertheless, there are enigmatic short-term gaps in the records of certain phenomena, such as a dramatic increase in those records of astrological significance in the few decades prior to the overthrow of the Chin dynasty (this effect is seen for other dynasties also). The completeness of the astronomical records was carefully investigated for the sunspot gaps which we mentioned earlier.

Red gap (1) — Continuity of astronomical records during this period would be extremely difficult to investigate and interpret in detail, since it was a time when China suffered numerous divisions and the "gap" of interest encompasses several relatively short-lived dynasties. Only during the Wei (386 to 535 A.D.), the longest-lived dynasty of this period, do any sunspot records appear. The uncertainties in the completeness of the astronomical records would not allow an unambiguous interpretation of this gap as a genuine solar activity protracted minimum.

Orange gap (2) — Not a single spot is reported between 580 and 820 A.D. This period is almost completely encompassed by the long-lived T'ang dynasty (618 to 907 A.D.), noted for its literary rather for its scientific activity. However, analysis of the frequency of recording of the celestial phenomena gives us no reason to believe that the astronomical records are incomplete for this era. Nine sunspot sightings are recorded for the final century of the dynasty. There are other indicators which tend to confirm that this gap represents a genuine protracted minimum in solar activity.

Yellow gap (3) — The period of interest (980 to 1600 A.D.) was during the Sung dynasty (960 to 1279), a time of great cultural and scientific enlightenment in China. However, the deplorable state of astronomy during the early decades of the dynasty is well documented, and was only rectified about 1070 A.D. with the appointment of P'eng Ch'eng as Astronomer Royal. This gap was still too early for corroborative evidence from Korea. Under the circumstances, it would be difficult to interpret the absence of sunspot records in the interval of interest as reflecting anything other than the nadir of Sung astronomy prior to its renaissance under the direction of P'eng Ch'eng, and his successor Shen Kua.

Green gap (4) — This gap is almost exactly coincident with the rule of the Yuan dynasty (1279 to 1368 A.D.), which might at first imply that the absence of sunspot records reflects a social rather than an astronomical influence. This is too simple an interpretation, since records from Korea (about equal in number to Chinese records during the previous century and following half century) also stop about 1280 through about 1350 A.D. In addition, the occupying Mongol rulers retained Chinese scholars in such important appointments as court astronomers, and indeed encouraged close collaboration between Chinese and Muslim (Persian and Arab) astronomers. Our investigations show that other daytime astronomical phenomena appear to have been adequately documented throughout the Yuan dynasty, and the gap appears to lend itself to an interpretation in terms of solar *in*activity.

Blue gap (5) — Only two sightings are reported from a full two centuries. This period is completely covered by the Ming dynasty (1368 to 1662 A.D.). From the first two decades of the dynasty there is a wealth of sunspot records, and again several from the final few decades. While it's true that astronomy seems to have shared the general decline of science during the Ming dynasty, following its pinnacle in the Sung, the records of all other astronomical phenomena appear nevertheless to be comparatively complete. The gap is also apparent in the Korean records.

On the basis of the above discussion, it is tempting to interpret the orange gap (2), green gap (4) and blue gap (5) as solar activity protracted minima, similar to the now well-established Maunder minimum of 1645 to 1715. This interpretation is given further credence from an analysis of other indicators of solar variability, and in particular from the occurrence of certain atmospheric isotopes.

The isotope carbon-14 is produced in the upper atmosphere as a result of cosmic ray bombardment. Neutrons produced by an initial influx of cosmic rays collide with nitrogen-14 atoms with the resulting ejection of protons to leave carbon-14 atoms. The cosmic ray flux reaching Earth is partially shielded by the extended magnetic field of the sun. At times of maxima in solar activity, the shielding effect is greater than at times of solar activity minima. Thus carbon-14 production is expected to be highest at times of low solar activity, and vice versa.

Carbon-14 (along with the more prevalent carbon-12 isotope) is assimilated as carbon dioxide in the photosynthesis process, and preserved in living trees and well-preserved dead wood spanning a period of 7,000 years. Unfortunately the 11 year solar cycle is smoothed out in the carbon-14 history established from tree rings. Nevertheless, gross excursions in solar behavior would be expected to reveal themselves, and indeed Eddy has shown that the Maunder minimum coincides with a pronounced carbon-14 deviation commensurate with a protracted period of low solar activity. He also drew attention to a similar pronounced departure centered about two centuries before the Maunder minimum, which he called the Spörer minimum. The Spörer minimum appears to have revealed itself in the historical sunspot data as our blue gap (5), from about 1400 to 1600. The carbon-14 history is also suggestive of low solar activity during periods near-coincident with our orange gap (2) and green gap (4), although confirmation of this fact requires improved tree ring data and a more detailed consideration of the completeness of the historical records.

Thus it appears that major protracted excursions in solar activity are preserved in the terrestrial carbon-14 history, with the incidence of naked eye sunspot sightings providing circumstantial evidence for such excursions. It is now important that the carbon-14 history be improved by including measurements from trees giving as wide as possible a geographic coverage (so that it truly reflects global rather than merely local anomalies), and that the data be subjected to the most critical possible interpretation in an attempt to extract a history of solar activity over a full seven millennia.

Eddy, by confirming the reality of the Maunder minimum in sunspot activity, has finally broken the shackles which have bound solar physicists for two centuries to a sun behaving with persistent regularity.

◆

Dr. David H. Clark of the Royal Greenwich Observatory and Dr. F. Richard Stephenson of the Institute of Lunar and Planetary Sciences, at the University of Newcastle-Upon-Tyne (England), are the co-authors of **The Historical Supernovae.**

ASTRO-NEWS

Latest News From the World of Astronomy

Venus Mission a Success!

Pioneer Venus 1 and Pioneer Venus 2, the complex United States space probes sent to investigate Earth's closest neighbor, performed nearly perfectly upon their arrival at the veiled planet last December.

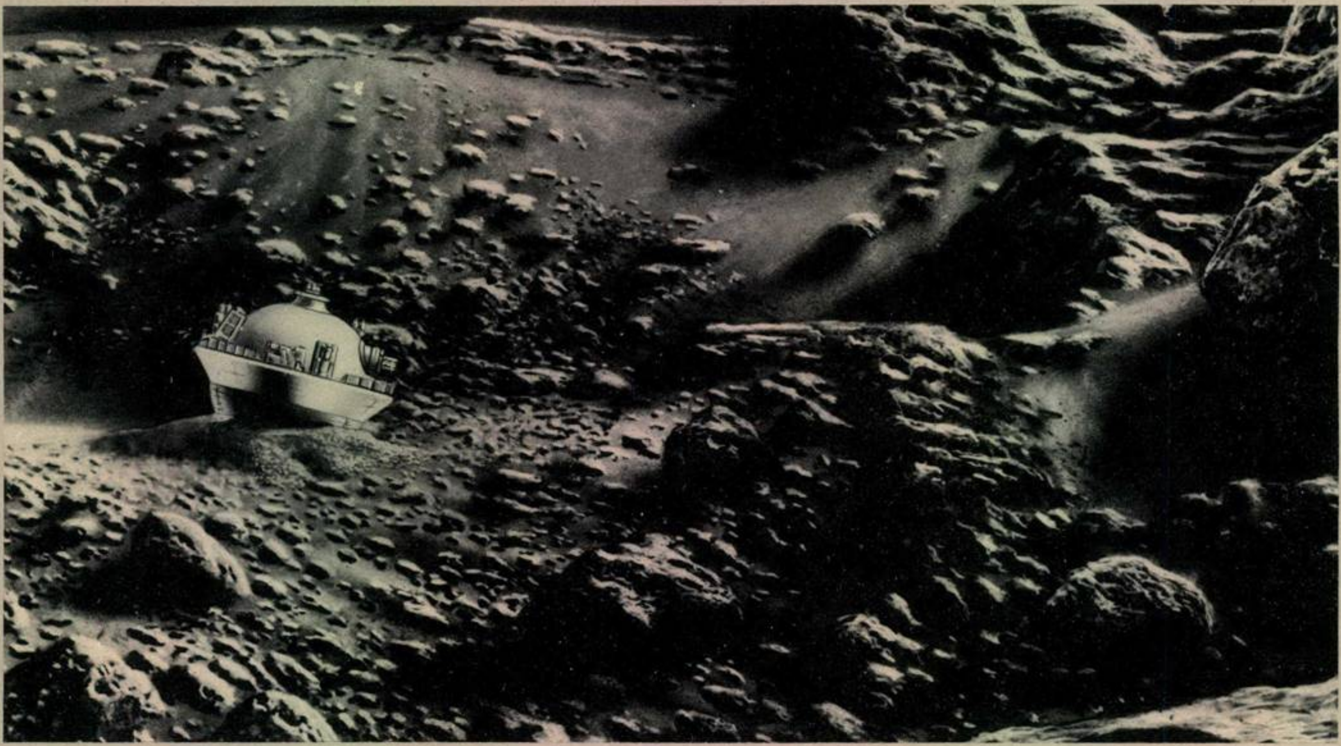
Right on schedule, the Pioneer Venus 1 (PV-1) orbiter took up its station on Dec. 5. It is designed to circle Venus in an elongated orbit for at least one full Venusian day (243 Earth days). Two minor problems delayed the start of its reconnaissance program, but the primary mission will not be affected since an extension has already been approved.

One problem was caused by an overburn of the orbital injection engine, which resulted in a shorter orbital period than desired. PV-1 was to complete each orbit in exactly 24 hours, so that its occultation by the planet would occur at the same time each Earth day. This is necessary because the only two stations capable of making the proper occultation measurements are the Goldstone, Calif. and Canberra, Australia Deep Space Network Stations, and Venus must be in sight of one or the other at the times of occultation. The orbit was adjusted to the proper parameters by selected thruster burns. It now has a periapsis (low point) of about 100 miles, swinging out to an apoapsis (high point) of about 40,000 miles once each Earth day.

The other problem which caused a delay in full operational status was the transmission of an incorrect signal to the probe during its first orbit. The radar experiment was turned on at the wrong time, resulting in useless data being returned. The mistake will not effect future performace of the experiment.

The first ultraviolet image, returned on Dec. 6, was something of a disappointment to project scientists. A low contrast picture, it still failed to show any markings even after computer processing. Although the total absence of any cloud features was unexpected, experimenters speculat-

Venus *continued on page 56*



The large Sounder Probe, one of the four probes of Pioneer Venus 2 which descended to the surface of the planet at widely separated points, is shown after impact in this artist's conception. Though the probes were not designed to survive surface impact, the small Day Probe did and then lasted for 67 minutes despite the extremely high temperature and pressure on Venus' surface. Project scientists theorize it may have made a relatively soft landing in dust or ashes. NASA artwork.

Researchers Detect Gravity Waves

A research team at the University of Massachusetts has announced the first experimental evidence directly supporting the existence of gravitational waves.

Such waves, long hypothesized but never directly observed, are in some ways similar to radio waves, but are based on the forces of gravity rather than those of electricity and magnetism. The existence of gravity waves is one of the long-standing — but heretofore untested — predictions of Einstein's general theory of relativity.

The discovery was presented by Dr. Joseph H. Taylor, professor of astronomy at the University of Massachusetts, to a symposium on relativistic astrophysics held in Munich, West Germany, last December. The symposium was attended by several hundred leading astrophysicists from Europe and North America.

Taylor's colleagues in the experiment included Dr. Peter M. McCulloh, on temporary leave from the University of Tasmania (Australia), and Lee A. Fowler, a graduate student.

The new experimental data came as the result of a four year program of monitoring the radio emissions from a pulsar located some 15,000 light-years from Earth, in a distant portion of our galaxy. This pulsar, discovered in 1974 by the same research group, is known to be orbiting another massive object — perhaps another pulsar, or a black hole — because its repetitive beeps of emission speed up and slow down over a regular pattern lasting a little less than eight hours.

The pulsar used in the study is the only one known to be a member of an orbiting pair, Taylor said. Because it moves at a speed of over 660,000 m.p.h. and is subject to the very strong gravitational forces exerted by its companion, this pulsar is uniquely well-suited for detection of the effects of gravitational waves.

Einstein's theory predicts that such a system should emit gravitational waves which slowly extract energy from the orbit, thereby causing the pulsar and its companion to move closer together. As the size of the orbit decreases, the length of time required for the pulsar to complete an orbit also decreases. According to Taylor, leader of the group making the observations, relativity theory predicts that the orbit period should decrease at a rate of 1/10,000 second per year. The measured amount is almost precisely this value, or about 4/10,000 second since late 1974. Thus an important prediction, based on an application of Einstein's theory that could not have been foreseen 60 years ago, has been verified.

Observations of the orbiting pulsar were made with the largest radio telescope in the world, the 1,000 foot diameter antenna located near Arecibo, Puerto Rico. Operated by the National Astronomy and Ionosphere Center and also funded by the National Science Foundation, the Arecibo telescope is the only one sensitive enough to make accurate measurements of the distant orbiting pulsar.

Taylor said the finding will give much impetus to experimental work underway at numerous laboratories around the world, directed to actual detection of the gravitational waves themselves, as well as to further theoretical studies of the general theory of relativity. Gravitational waves have yet to be detected directly in the laboratory. Such experiments are extremely difficult to perform because of the very low intensity of gravitational waves arriving at Earth.

Venus *continued from page 55*

ed that the agent responsible for ultraviolet absorption, and hence the markings seen in images from previous missions, must lie below the upper layers of the atmosphere. The first image showed Venus as a crescent, and with that angle of illumination only the very top parts of the clouds were seen. Later photos of Venus (about 500 are expected to be taken) should show a full disk, revealing features deeper in the cloud layers.

Four days after PV-1 was injected into orbit, the second probe arrived at the planet. Known as the multiprobe, PV-2 had already split up into five separate probes. One of the five, the bus or main vehicle, returned data before burning up in the upper atmosphere as expected. The other four descended more slowly through the atmospheric layers, performing a number of observations before impact on Venus' surface.

Although none of the four had been expected to survive impact, one probe continued returning data for an additional 67 minutes from the ground. Project scientists speculated that it had made a relatively soft landing in dust or ashes. If so, this would be the first evidence that Venus' surface is not universally hard and rocky.

Two surprising discoveries have already been made by the Venus mission. One was the result of a slowing of the solar wind detected by the orbiter the first few days after it began its measurements. The speed of the wind, composed of charged particles streaming out from the sun, had been dropping from its first measured value of 280 miles per second down to 155 (considered very slow for the solar wind), when it suddenly shot up to 370 miles per second. Probably because of the slow wind, the altitude of Venus' ionosphere rose from 155 to 930 miles. Surprisingly, the ionosphere of Venus seems to be about as effective as Earth's magnetosphere in warding off the solar wind. As expected, Venus has not been observed to have a magnetosphere, which deflects charged particles along lines of magnetic force.

Another discovery was the detection of unusually large amounts of the inert gas argon in Venus' atmosphere. Furthermore, the proportion of the isotope argon-36, a relatively rare form of the element on Earth, was much higher than expected. This means that Venus may have a significantly different elemental composition. If so, then current theories of planetary formation, which predict similar elemental abundances for the inner planets of the solar system, may have to be drastically revised.

Data from the atmospheric probes continues to be correlated and analyzed, building up a detailed picture of the structure of Venus' atmosphere. Preliminary analysis from the sounder probe, the largest and most sophisticated, has already indicated that there are three distinct layers of clouds. The clouds appear to be composed of sulfuric acid droplets, but the lower layers seem to have particles of dust or elemental sulfur in them. The lowest layer of clouds may possess liquid sulfur compounds in addition to sulfuric acid.

As the orbiter PV-1 continues its mission, the dynamics and structure of the Venusian atmosphere should become better understood. The orbiter will also continue to make measurements of the ionosphere and the solar wind. Another important result expected is the exact distribution of matter within the body of Venus, determined by the effect of Venus' gravity on the orbit of PV-1. An asymmetric distribution would account for the strange rotational lock with Earth displayed by Venus. (Whenever Venus is closest to Earth, it has the same side turned toward us.)

The success of the Pioneer Venus mission has raised scientific hopes for a better understanding of Earth's sister planet.

Standard Astronomy Instruments Planned

One problem with past space missions is that each required a custom built set of experiments that would never be used again. The result was higher costs and occasional frustration when an experiment failed.

NASA, though, and two other agencies are planning astronomy instruments that could become standard equipment for the Space Shuttle in the 1980s.

NASA's multi-user instrument program was announced last September by Dr. Noel Hinners, associate administrator for space science.

"These instruments will be operated similar to ground based astronomy observatory programs," Hinners said, "in that proposals to utilize these instruments will be solicited and selected on a competitive basis. The existing Spacelab announcement of opportunity will be used for this process.

"In this way, many investigators will be offered the opportunity to utilize these large instrument facilities to collect data and perform their own experiments with specialized focal plane instruments."

Hinners said that six candidates had been selected by 16 top scientists. The astronomy experiments are:

- a solar optical telescope, a broad band optical telescope with ultrahigh spatial resolution;
- a 1.8 meter infrared telescope using supercooled optics and instruments for imaging and spectrographic studies of stars forming and other dark objects, and
- a large area modular array to provide high sensitivity and spatial resolution to x-ray astronomers.

The other three experiments, for terrestrial studies, are a laser ranging instrument to study particles and aerosols in the atmosphere; a chemical release module to study the magnetosphere and ionosphere, and a cryogenically cooled, limb-scanning interferometer radiometer to study chemical activity in the upper atmosphere.

Hinners also said top priority projects for the next decade are the gamma ray observatory, for which experiments have been selected, and the advanced x-ray astrophysics facility, a meter-class x-ray telescope based on the Space Telescope and the second High Energy Astronomy Observatory.

The Naval Research Laboratory (NRL) also announced that it is developing two ultraviolet cameras for use aboard the Shuttle.

Both cameras will use image boosting electronics similar to those developed for military night scopes. Because ultraviolet objects usually do not produce enough photons to make a decent film image, showers of electrons triggered by the photons will be used instead. A similar camera was built by NRL for use on Apollo 16 to photograph Earth's thin hydrogen envelope, and aboard Skylab to photograph comet Kohoutek. NRL wants to use the cameras for ultraviolet sky surveys.

Los Alamos (N.M.) Scientific Laboratory is proposing two telescopes to study the sun: an x-ray imaging spectrometer polychromator (XRISP), and a hard x-ray imaging instrument (HXII).

"XRISP would simultaneously provide high resolution images and

Instruments *continued on page 58*

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Instruments *continued from page 57*

high resolution spectra," according to Richard Blake of Los Alamos. "Its sensitivity and diagnostic capabilities would be at least 100 times better than any x-ray experiments flown or now on the drawing board. We could do much more detailed studies of the buildup and release of energy in the sun's corona, for instance."

XRISP would use a massive collimator assembly and seven sets of scattering crystals and proportional counters. Although its $15 million cost is about 30 times that of a sounding rocket flight, it will be more cost effective by producing 1,000 times as much data per second with far greater resolution.

HXII would be usable for stellar as well as x-ray studies. It would produce telescopelike images in the hard x-ray region that present x-ray telescopes cannot use. This would be accomplished by a large collimating array with proportional gas counters.

Each experiment would occupy a space about one by one by three meters long, meaning they could operate side-by-side on the same pallet. Indeed, Los Alamos Scientific Laboratory has recommended that as the best way to use the two.

Eclipse Accommodations Available in 3 Places

Many of you may want to see the eclipse but have not yet made plans or found accommodations. Jim Gall, of Toronto, has just returned from the eclipse area, and has passed along some last minute useful information.

Don't go to Brandon unless you have reservations. It'll be jammed with crowds from the Canada Winter Games, and there's no space left! But here are three good central line locations that are prepared to absorb large crowds.

Auborg, Manitoba: Ms. Carol Aitken (204-376-2289) will organize billets for eclipse watchers in the local schools and public library. "Nobody will be cold" — it'll be indoor camping in hallways and schoolrooms. Auborg is right on the central line, and will have 2 minutes 52 seconds of totality.

Riverton, Manitoba: Thor Johannson (204-378-5505, work/204-378-2726, home), a local schoolteacher, will organize billets. Riverton's "Festival of the Solar Eclipse" will feature an ice carnival and hockey tournament on Friday, a curling bonspiel, a poker derby, snowmobile race on Saturday, a dance on Saturday night and Bingo on Sunday. These Canadians will also demonstrate igloo building!

The Clark Leigh Farm: Mr. Leigh (204-942-4315), a well-known farm broadcast announcer, will host eclipse-goers at his farm — there are 150 acres of field and bush available for camping, and some places with electricity. He'll serve coffee in the barn, and a ladies privy will be available! You must call in advance.

In addition, the Winnipeg Army Surplus Store will be open from 6 p.m. to 10 p.m. Sunday night to sell warm clothing for eclipse viewers. Be sure to call in advance to arrange accommodations.

Harvard Magazine takes you on remarkable journeys

Can a cowboy from Birdville, Texas, cross the English Channel in a canoe drawn by kites, shoot glass balls off his head by firing at the trigger of a pistol locked in a vise twenty paces away and trained at the top of his head, narrowly avoid ramming St. Paul's Cathedral in a dirigible, and become the first person to fly an airplane in the British Empire?

Of course—as you'd learn from a Harvard Magazine profile of Samuel Franklin Cody, self-described "King of the Cowboys." Harvard Magazine introduces you to fascinating figures from history . . . keeps you up to date on science and the arts . . . lets you visit laboratories and expeditions where exciting discoveries never stop.

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HARVARD
Magazine

New Theory Accounts for Rings of Uranus and Saturn

The rings of Uranus are shaped like horseshoes, with an unseen satellite in each horseshoe's gap, according to a remarkable new theory by astronomers Stan Dermott and Tom Gold of Cornell University, and Andrew Sinclair of the Royal Greenwich Observatory.

Dermott and Gold had previously proposed that the rings of Uranus were crescent shaped (see Astro-News, October 1977), but subsequent study showed that model to be untenable. This new theory, presented at the Royal Astronomical Society, takes into account the latest observations of the rings, made during the occultation of a star in April 1978 (Astro-News, July 1978). The theory also explains the differences between the rings of Uranus and those of Saturn, and predicts the existence of other rings systems.

Among the striking features of the nine Uranian rings now known are that they are narrow and have sharply defined edges. The April 1978 observations showed that the rings are apparently elliptical — particularly the outer ring labeled Epsilon. This ring also varies in width, widening from 20km across where it is closest to Uranus to 100km at its farthest.

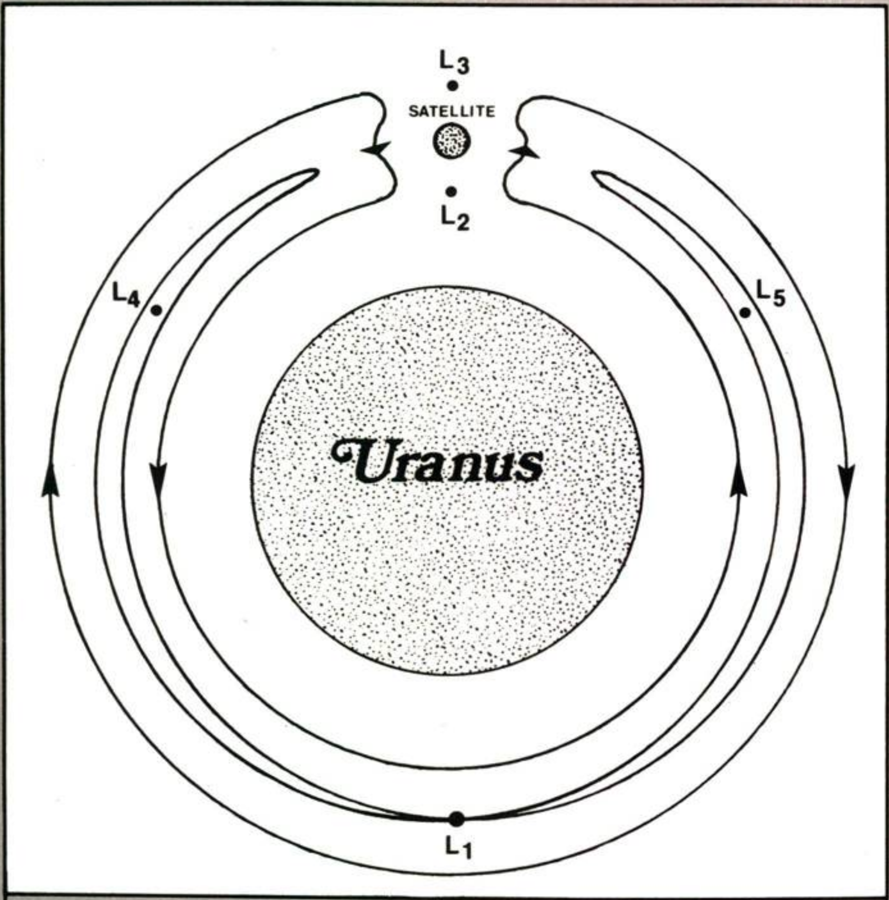
Dermott, Gold and Sinclair think that a clue to the origin of the rings is that Uranus spins rather slowly on its axis; one recent figure for its rotation period is 24 hours. Therefore a satellite in a synchronous orbit around Uranus (an orbit with the same period as the planet's rotation) would be rather far from the planet. This would leave plenty of room for satellites to form closer to Uranus. But a satellite that was closer to Uranus than the synchronous orbit would slowly spiral toward the planet because of the effect of tidal drag. The satellite would eventually enter the critical Roche zone, where it would be broken up by gravitational forces.

Saturn is a different case because it rotates more quickly than Uranus. A synchronous orbit around Saturn lies within the Roche zone, where satellites could not form. A satellite forming outside Saturn's Roche zone would automatically be above synchronous height, and would be driven away from the planet by tidal forces. Therefore it does not seem possible for a satellite to enter Saturn's Roche zone, and so the rings of Saturn cannot be the result of the breakup of a former moon. They must instead consist of particles that have always been within the Roche zone, or of particles which spiraled inward due to the drag caused by sunlight known as the Poynting-Robertson effect.

But what keeps the rings of Uranus on such well-defined paths? The secret here seems to be that when the one or more Uranian moons spiraled into the Roche zone, they broke into several smaller fragments, each of which now acts as the parent body of a ring. Particles are being pulled off the fragments by tidal forces, and the particles are kept in narrow orbits by the parent fragments' gravitational influence.

According to Dermott, Gold and Sinclair, the ring particles follow horseshoe paths around the Lagrangian libration points (L_1, L_4 and L_5) of the parent body's orbit. This model accounts for the observed eccentricity of the rings, which is caused by the ellipticity and inclination of the parent bodies' orbits.

Since Neptune is another slow spinning planet (latest observations suggest its rotation period is similar to that of Uranus), the three astronomers predict that it, too, may have horseshoe shaped rings formed by the breakup of former satellites. And they predict that Mars will have a ring in the next million years, caused by the orbital decay of Phobos. Indeed, it may even have a faint ring today, caused by loose matter torn off the surface of Phobos.



Particles in the rings of Uranus may orbit in strange horseshoe shaped paths as pictured above, according to a new theory of their origin. A satellite which has spiraled in too close to Uranus has come within the Roche limit, the theoretical boundary within which the gravitational force of Uranus becomes disruptive and begins to break up the body of the satellite. Particles torn off the surface are forced by the peculiarities of the gravitational field around the planet and its satellite into paths around the Lagrangian points L_1, L_4 and L_5. The Lagrangian points are points in empty space at which the gravitational forces of the two bodies are in balance.

Meteorite Provides Clue to Formation of Solar System

How was the solar system formed? That mystery is now being illuminated by a group of American researchers looking at the structural detail of a meteorite that fell in northern Mexico in 1969. It seems a fairly improbable connection to make, yet scientists believe it's good enough to enable them to predict that two million years before the collapse of the gas and dust cloud that was to form the sun and its planets, a supernova exploded nearby and thereby possibly triggered the actual collapse.

The meteorite that holds the key to this prediction is the two-ton Allende meteorite. The object itself is not a homogeneous mass of rock, but an agglomeration of mineral species. The most widely accepted theory of meteorite formation says such objects formed at the same time as the sun and planets. Preserved within the meteorites, there might be telltale signs of the processes that happened on the eve of the solar system's creation. On planets such as Earth, any signs would have been destroyed long ago by processes such as weathering and thermal reassortment. Meteorites have not suffered these fates, and can be regarded as "fossils" dating back to the time of the solar system's creation.

The meteorites, planets and other solid objects that were formed came from a collapse of a progenitor dustcloud which would have contained hydrogen and helium, as well as the heavier elements. These heavier elements would have been made by the classical process of nucleosynthesis — the cascade of element building by fusion that occurs during the course of a star's lifetime. Supernovae are great nucleosynthetic generators because they contain sufficient matter and energy to form from hydrogen and helium, the heavy atoms that characterize the world we see around us. Astrophysicists are confident they can account pretty well for the abundances of the elements we see in the universe.

All elements have different isotope species. By looking at the abundances of the various isotopes, it's possible to produce a set of isotope ratios that are characteristic of the kind of matter here on Earth. For instance, moon rock and Earth rock have roughly the same ratio of oxygen-16 to oxygen-18 — about 500 to 1. Against a normal pattern of isotope abundances, it might be possible to find isotope abundance abnormalities in objects that have had different geological histories — objects such as meteorites.

This was confirmed about five years ago by Robert Clayton and his co-workers at the University of Chicago. They discovered that some meteoritic material contained unusually high proportions of the isotope oxygen-16, while the same object showed a terrestrial ratio for the abundances of oxygen-17 and oxygen-18. This contradiction in the isotope ratios has shown up in isotopes of such diverse elements as magnesium, barium, krypton and xenon, among others.

One of the important centers for these studies has been the Charles Arms Laboratory of the California Institute of Technology in Pasadena. There, Gerry Wasserburg and his colleagues have developed very sensitive mass spectrometry techniques for measuring the minute quantities of differing isotopes that reside in the crystalline fragments recovered from meteorites. Using these techniques, it's now possible to measure the abundances of magnesium isotopes, for example, in materials that may contain as little as 10^{-8} grams of magnesium. Wasserburg's group studied magnesium because it can be synthesized in at least two ways — by direct manufacture in a supernova, or by radioactive decay of aluminum-26. Since the isotope magnesium-26 accounts for 11 percent of the magnesium we see in terrestrial material, any anomaly in its abundance in meteoritic material might be interpreted as being caused by the special formation conditions of meteoritic grains and the preservation of such material in its original form during the long flight around the solar system.

Wasserburg's group sought crystals from the Allende meteorite that came from fragments free of contact with magnesium bearing minerals, because any heating of the meteorite could have produced a diffusion of magnesium leading to uninterpretable results. The specimen originally chosen was a crystal of anorthite which, in principle, should contain virtually no magnesium, or at least at the level of impurity.

They found that the Allende anorthite contained excessive quantities of magnesium-26, whereas the ratio of magnesium-25 to magnesium-24 was essentially at the terrestrial level. The excess was 10 percent above the normal level! How did the excess magnesium-26 get there? Wasserburg concluded the magnesium-26 excess was produced by radioactive decay of aluminum-26, and that this decay happened after the anorthite crystal had been formed.

How does this argument have any bearing on the formation of the solar system? Aluminum-26 has a half-life of 720,000 years, and it is formed, together with all other heavy elements, in the explosive phase of a supernova. It must, therefore, have been incorporated into the Allende anorthite fragments before the bulk of the isotope decayed radioactively. The theory strongly suggests that a supernova must have exploded within a few aluminum-26 half-lives, quite near the gas cloud that was to condense to become our solar system. It seems plausible to extend the argument further and suggest that this explosion may have been the triggering event that led to the collapse of that gas and dust cloud.

Late last year this hypothesis received support from a theoretical analysis done by James Latimer of the University of Illinois and David Schramm and Lawrence Grossman of the University of Chicago. They looked at the various processes of element formation that happen in supernovae and attempted to correlate them with the production of minerals that could be formed as the hot supernova gases cooled on expansion. Their work indicates that a fairly extensive catalog of minerals could condense in this manner and, in the form of grainy ejecta, could be blasted off by the supernova. These grains could have peppered the gas and dust cloud like shrapnel, introducing into it hard minerals that could have been incorporated into objects such as the Allende meteorite.

Wasserburg's group has dubbed the Allende meteorite the Pandora's box of the nuclides; there's no doubt this box may hold more clues on the origin and formation of our planetary system.

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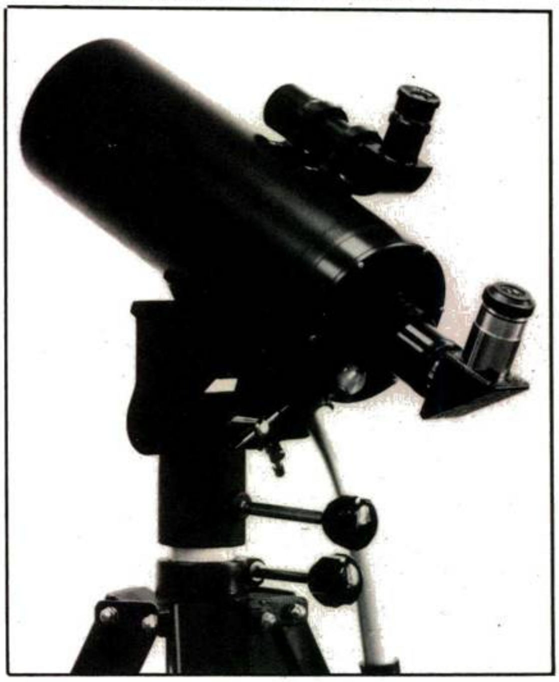

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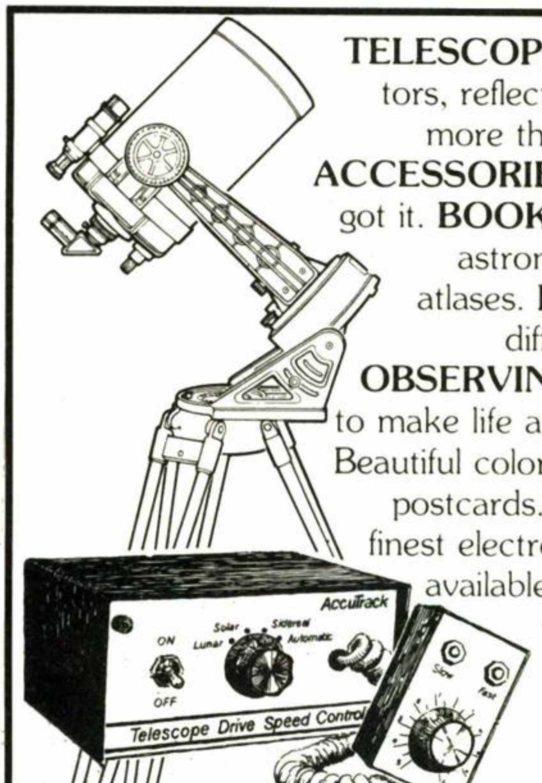

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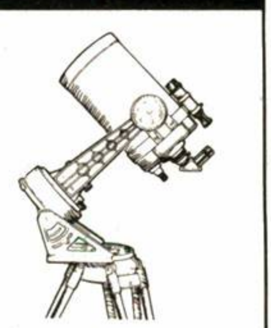

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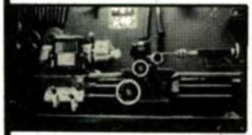

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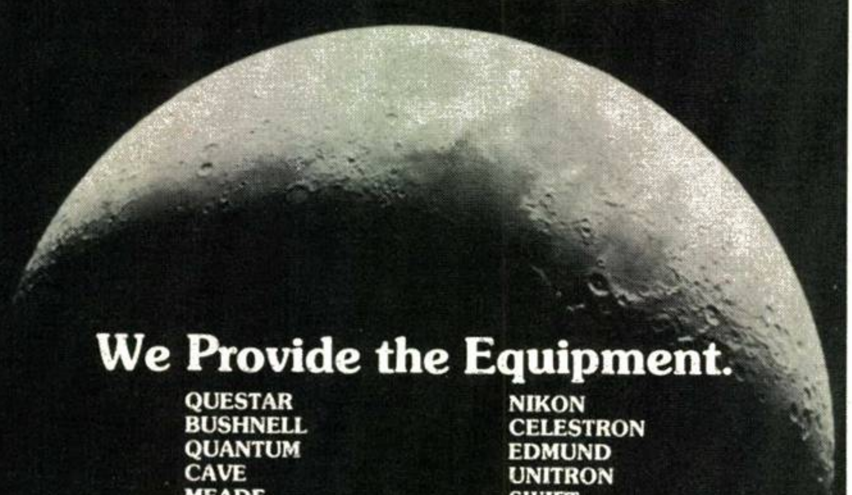

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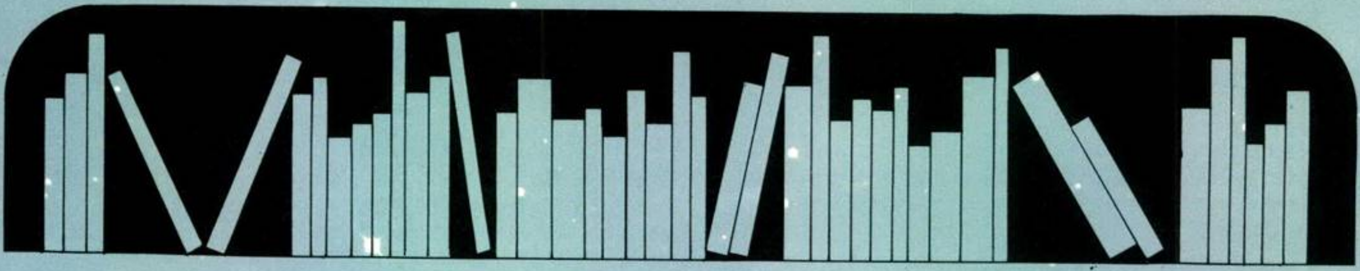

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by ISAAC ASIMOV

196 pages, hardcover, $8.95
Walker and Co. (1977)

Isaac Asimov needs no introduction. No doubt he's known to everyone interested in science or science fiction, and as most of his fans know, he is now well on his way to his 200th book. Many of his books are on astronomy, and **The Collapsing Universe** is reminiscent of his earlier **The Universe**. Many of the same topics are covered in it. In **Opus 100** (his 100th book), Asimov talked about this book: He told how an editor from Walker and Co. asked him to write a small book on the then-recently-discovered quasars, and "jumped at the chance". But, in writing the book, he found he had to first talk about a few things that came before quasars, and then a few things that came before that, etc. So by the time the book finally came out, it began with, "In 600 B.C. ...."

Asimov seems to have done almost the same thing in this book. It's billed as "the story of black holes", but he begins by explaining what an atom is. (His object in doing this is to introduce the first of the four fundamental fields of nature.) From there he goes to the planets, then to compressed matter, white dwarfs, neutron stars, and finally one chapter near the end he gets to black holes.

The fact that the book is supposed to be about black holes but contains only this one chapter is strange. Asimov's idea, of course, is to give the reader sufficient background to understand the concept — but 150 of its less than 200 pages?

A positive feature of the book is Asimov's breezy readable style. The book follows a logical pattern going from the more familiar to the less familiar, as it would generally be understood by the lay reader. For the most part the discussions are clear — but there are exceptions.

Chapter one, for example, might seem difficult and perhaps a little confusing to the uninitiated. But on the other hand, to someone generally familiar with the subject, it might appear oversimplified. Asimov goes to great lengths to explain the atom and its constituents, but at the same time includes several formulas (10 in the first two chapters) and detailed math which would probably cause the novice some difficulty.

The last chapter is an excursion into cosmology with a discussion of the beginning and ending of the universe. Asimov seems to be really letting himself go in the first few pages. In fact, he seems to be just having fun with speculation. It's interesting to read, but not to be taken too seriously.

The book's generally quite accurate, but there are some errors (mostly typographical). He implies that H.D. 226868 is a red giant; it isn't. And he has UHURU being launched in 1969 when it was launched in 1970.

As a first book on the subject, it's recommended; some readers may be disappointed, however, with the brevity of material on black holes. *Barry Parker.*

◆

Space and Time in the Modern Universe
by P.C.W. DAVIES

232 pages, hardcover, $13.95*
Cambridge University Press (1977)

Space and time are so familiar that almost everyone takes them for granted. They are basically simple concepts — or are they? Recent discoveries in astronomy and physics indicate that this may not be the case. We may be faced with situations where drastic changes in their character occur.

In this carefully written and technical account of space and time, Davies does an admirable job of conveying the essence of these terms. His explanations are clear and accurate. The book is, however, intended for a relatively mature layman. According to the dust jacket, no knowledge of advanced mathematics is needed to understand the book and indeed, no advanced mathematics is needed (though there is some algebra in the book). The Lorentz transformations, for example, are derived. Some math is also used in discussing the four dimensional line elements. To get a complete (or nearly so) understanding of the book, you'd also need some understanding of the basic concepts of physics.

The book starts out with a detailed discussion of space and time in the classical Newtonian sense. Chapter two brings us to the overthrow of the simple Newtonian ideas, and special relativity is introduced. In chapter three Davies turns to thermodynamics. And with the introduction of concepts like symmetry of time, irreversibility and branch systems, the layman will find it heavier going.

Chapter four contains an excellent treatment of general relativity and black holes. A detailed explanation of how space and time change near a singularity is given.

Cosmology is the subject of chapter five. It's difficult to do justice to such a comprehensive subject in one chapter, but Davies does give a good introduction. Most of the chapter centers around the Friedmann models of the universe, but there's a brief discussion of the rival cosmologies.

Several different topics are treated in the last chapter; life in the universe is discussed in some detail. Also, Davies discusses a topic not usually found in books of this type: "How special is the universe?" There are, at present, two points of view regarding this. On the one side there is the view that our universe could have resulted from almost any set of initial conditions. The other believes that our universe is so symmetric and homogeneous that it required very special initial conditions. Davies talks over these two points of view.

The book's best suited for someone with a slight background in physics, and for this person it's highly recommended. *Barry Parker.*

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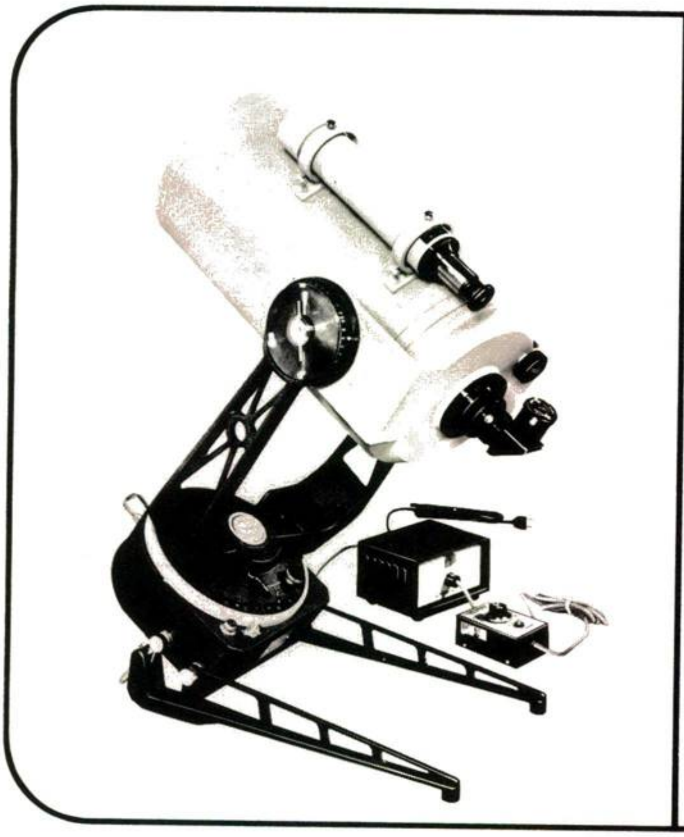

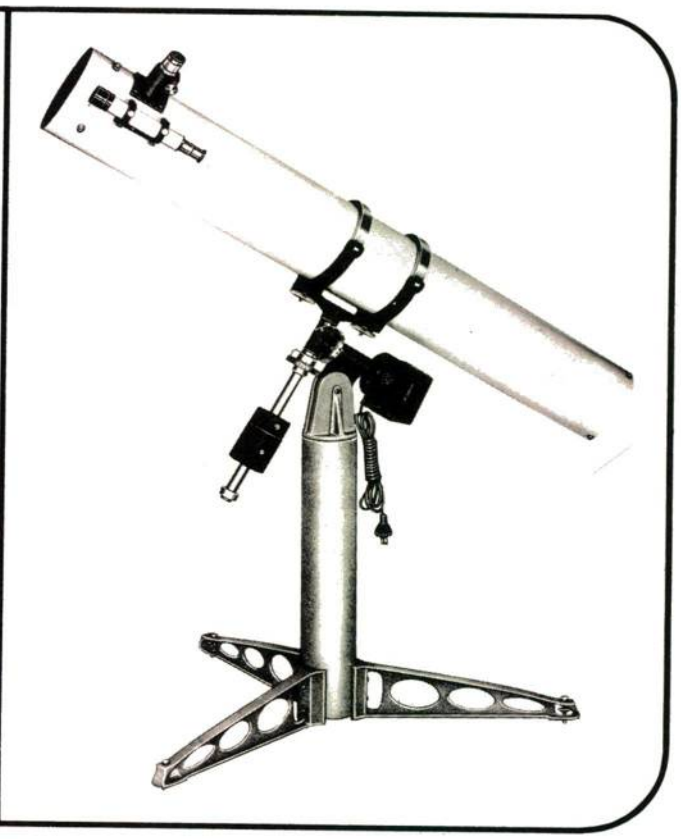

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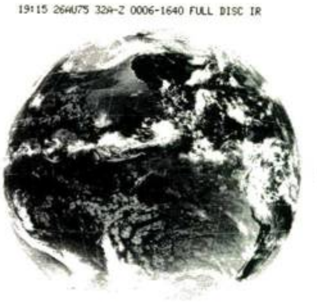

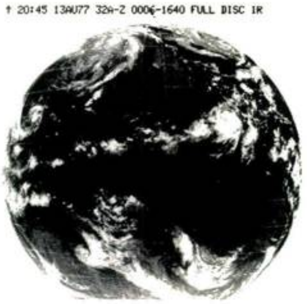

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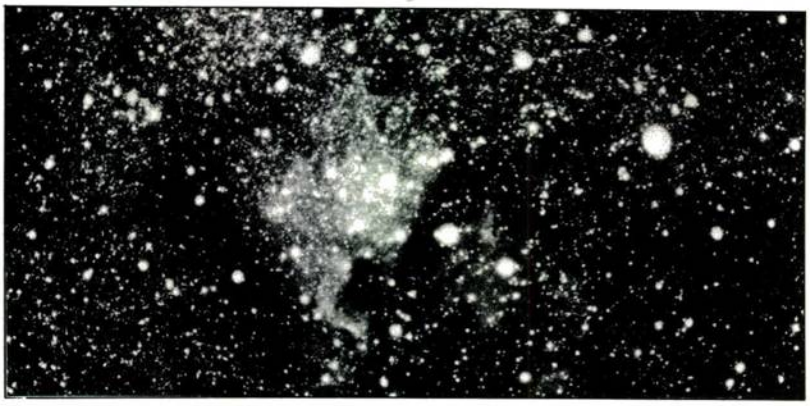

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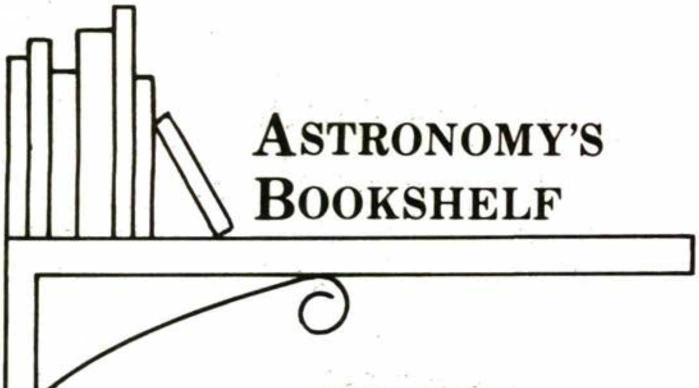

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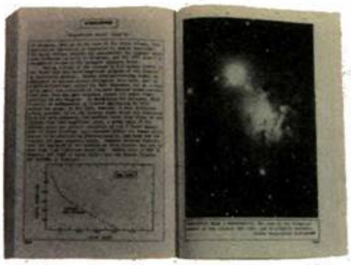

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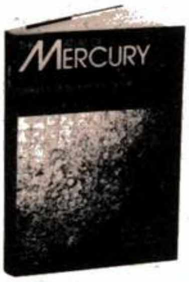

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NEW DEALER INQUIRIES INVITED

SPECIAL

STAR DOME

FEBRUARY

by

James Mullaney

and

Dewey Schwartzenburg

David Lindsay was an imaginative and creative young author who died young during World War I. His only published book, **A Voyage to Arcturus**, has long had a small but devoted following. It is an exotic, almost mystical work describing the rather supernatural travels of an Earth man among the strange inhabitants of a large planet (named Tormance) of the star Arcturus.

Arcturus is described as a binary star — which it is not — but then Lindsay's otherwise interesting book is not characterized by a great deal of scientific accuracy! Nevertheless, the description of the appearance of the two suns of Tormance is fascinating. It seems that the light of the primary, named Branchspell, is like that of our own sun — that is, composed of the three primary colors red, blue and yellow. But the other sun, Alppain, radiates an entirely different spectrum composed of blue and two other primary colors unknown on Earth: ulfire and jale. Lindsay attempted to describe the colors ulfire and jale by emotional analogy, pointing out that for us red evokes feelings of heat and passion, blue is delicate and mysterious, and so forth. In the same way, ulfire is painful and wild, and jale dreamlike, feverish and voluptuous! And just as all the other Earthly colors can be formed by combining the three primary colors in different ways, the three colors of blue, jale and ulfire were the basis of a literally un-Earthly spectrum!

All this fascinating speculation, of course, is scientific nonsense. The various colors of light are not actually caused by a mixture of three primary colors, though they can be approximated in that way. Each color is due to the particular wavelengths of electromagnetic radiation emitted or reflected by the objects we see. Of course our eyes perceive only a tiny part of the whole electromagnetic spectrum, ranging from what we call red at the shortest wavelengths to what we call blue at the longest. It could be argued that Alppain radiates over an entirely different part of the electromagnetic spectrum, but then our Earthly eyes would see nothing.

What, though, is the *true* cause of stellar colors? Why are some stars red, others yellow, and others blue? The answer is not as simple as you might think! To explain it, we're going to have to examine something that scientists call *black body radiation*.

A black body is not at all the same thing as a black *hole*, though there are some similarities. A black body is simply any object which absorbs *all* radiation falling on it. Since absolutely none is reflected, such an object is called a black body.

But a black body need not necessarily be black. Radiation which is absorbed, of course, will increase the energy content of an object unless it is gotten rid of in some way. One very efficient way of disposing of energy is by radiation. Thus a black body in thermodynamic equilibrium (maintaining a constant energy content) will radiate exactly as much energy as it receives. And this radiation will have a very characteristic form.

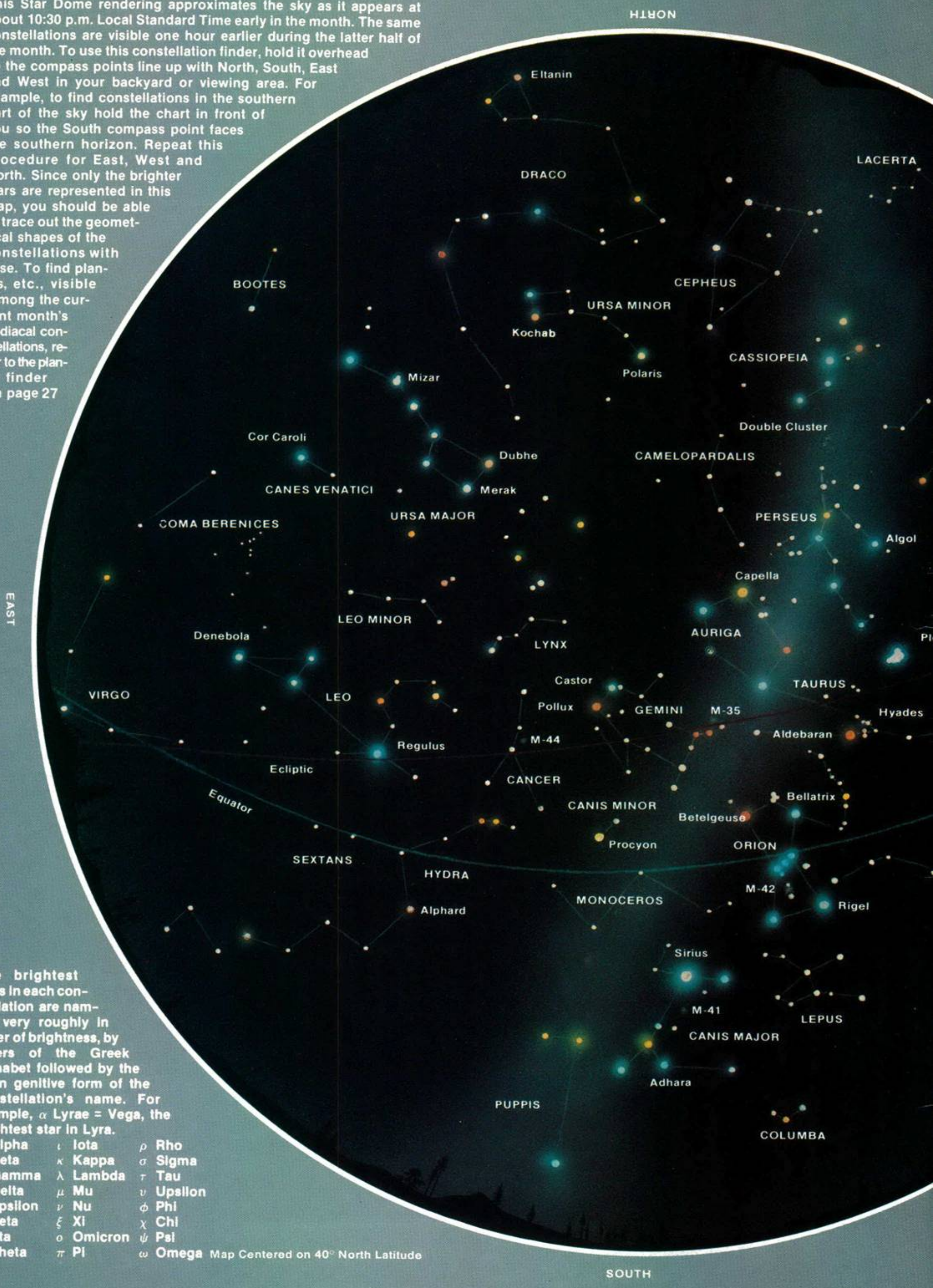
If you plot the amount of light emitted by a black body at each wavelength over a range of wavelengths, the curve which results will increase to a maximum and then slowly decrease. Thus the characteristic shape of the black body radiation curve somewhat resembles a lopsided bell. The wavelength at which the curve reaches a maximum represents the brightest radiation emitted by the black body.

Different black bodies may have different maximum wavelengths — curves which fall along different stretches of the electromagnetic spectrum. The difference is determined by the temperature of the black body. Temperature, of course, is nothing but a measure of the total energy of particle motion within a body; the "hotter" it is, the greater the turbulent motion of its parts. If energy is added to an object, its temperature increases — unless the added energy is released in some way, such as by radiation. If just as much energy is released as is received, the body is said to be in *thermodynamic equilibrium*.

Black bodies at high temperatures emit radiation with a maximum at a short (high energy) wavelength, while cooler ones emit less energy and the maximum of the light curve falls at a longer wavelength. A particular temperature is associated with a specific maximum wavelength, and thus, if that wavelength is known, the so-called black body temperature can be determined.

The surface of a star is a black body. It does not reflect radiation, but emits it, and it emits just as much energy in

This Star Dome rendering approximates the sky as it appears at about 10:30 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 27


NORTH
Eltanin
LACERTA
DRACO
BOOTES
CEPHEUS
URSA MINOR
Kochab
CASSIOPEIA
Polaris
Mizar
Double Cluster
Cor Caroli
Dubhe
CAMELOPARDALIS
CANES VENATICI
Merak
URSA MAJOR
PERSEUS
COMA BERENICES
Algol
Capella
EAST
LEO MINOR
AURIGA
Denebola
LYNX
Castor
TAURUS
VIRGO
LEO
Pollux
GEMINI
M-35
Hyades
M-44
Aldebaran
Regulus
Ecliptic
CANCER
Bellatrix
Equator
CANIS MINOR
Betelgeuse
Procyon
ORION
SEXTANS
HYDRA
M-42
MONOCEROS
Alphard
Rigel
Sirius
M-41
LEPUS
CANIS MAJOR
Adhara
PUPPIS
COLUMBA
SOUTH

Map Centered on 40° North Latitude

The brightest stars in each constellation are named, very roughly in order of brightness, by letters of the Greek alphabet followed by the Latin genitive form of the constellation's name. For example, α Lyrae = Vega, the brightest star in Lyra.

α	Alpha	ι	Iota	ρ	Rho
β	Beta	κ	Kappa	σ	Sigma
γ	Gamma	λ	Lambda	τ	Tau
δ	Delta	μ	Mu	υ	Upsilon
ϵ	Epsilon	ν	Nu	ϕ	Phi
ζ	Zeta	ξ	Xi	χ	Chi
η	Eta	o	Omicron	ψ	Psi
θ	Theta	π	Pi	ω	Omega

ANDROMEDA
M-31
Alpheratz
RIANGULUM
PISCES
ARIES
les
CETUS
Mira
ERIDANUS
WEST

Map by Adolf Schaller

the form of radiation as it receives from the interior of the star. Thus the surface is in perfect thermodynamic equilibrium, and the energy emitted at various wavelengths assumes the form of the black body curve.

That's why stars are colored! Still don't understand? Well, stars with a relatively low surface temperature emit most of their radiation in the long wavelength region of the spectrum — that is, in red. As the surface temperature rises, the black body curve of the star's radiation will shift more and more toward the short (high energy) end of the spectrum, shifting the star's color through orange to yellow and finally to blue. Of course some radiation is emitted at other wavelengths as well, since the black body curve is bell shaped, so the color of a star is never "pure" — confined to a single wavelength. And it's no coincidence that the black body curve of the sun pretty well spans the visible portion of the spectrum, with its maximum falling about in the middle at yellow. Our eyes have obviously evolved to fit the light we actually receive from the sun, which we perceive overall as white. We would expect the inhabitants of a planet around a very hot star, such as Sirius, to have eyesight far into the ultraviolet, where so much of their sun's light is emitted!

This is also how the surface temperatures of stars are determined by astronomers. By accurate measurement of the color of a star, its temperature can be derived directly. The hotter the star, the shorter will be its characteristic wavelength and so its color will be bluer, while cooler stars will be more red.

So when you look at the stars and note their colors, you are also able to tell their temperatures! Last month we asked you to compare the colors of Sirius, Rigel, Betelgeuse, Aldebaran, Capella, Castor and Pollux. Look at them again this month, and this time see if you can arrange them in order of increasing temperature. You'll be discovering a secret of the stars our ancestors never knew!

Close-Up

Canis Major Region

This month we descend below mighty Orion and move a little to the east to find ourselves in Canis Major, the great dog. This southerly constellation has the distinction of being home to the brightest star in the sky — Sirius. Indeed, Sirius may have given the constellation its name, for in ancient times (the reasons being lost in obscurity), Sirius was referred to as "the dog star". Of great importance to Egyptian religion, the first reappearance of Sirius from behind the sun, glimmering in the predawn sky, heralded the time of the Nile's flood and therefore the irrigation of Egypt's fields of crops. This appearance of Sirius is known as its *heliacal rising*, and was a central date in the ancient Egyptian calendar. Numerous myths clustered about the figure of the star, identifying it with several Egyptian divinities (including, logically enough the jackal, or dog-headed god Annubis).

In February, though, Sirius is far from the time of its heliacal rising. Instead, the brightest star in our sky, along with its constellation, is well-placed for evening observation. Those in the south will find it much higher in the sky than those living at more northern latitudes — and no doubt will find these winter evenings warmer and more comfortable for exploring the wonders of Canis Major!

Sirius

Blazing at visual magnitude -1.4, this A type blue-white gem is the brightest star in the entire heavens aside from our own sun. It is also one of our nearest stellar neighbors, lying just 8.7 light-years away — only twice the distance of the famed Alpha Centauri system.

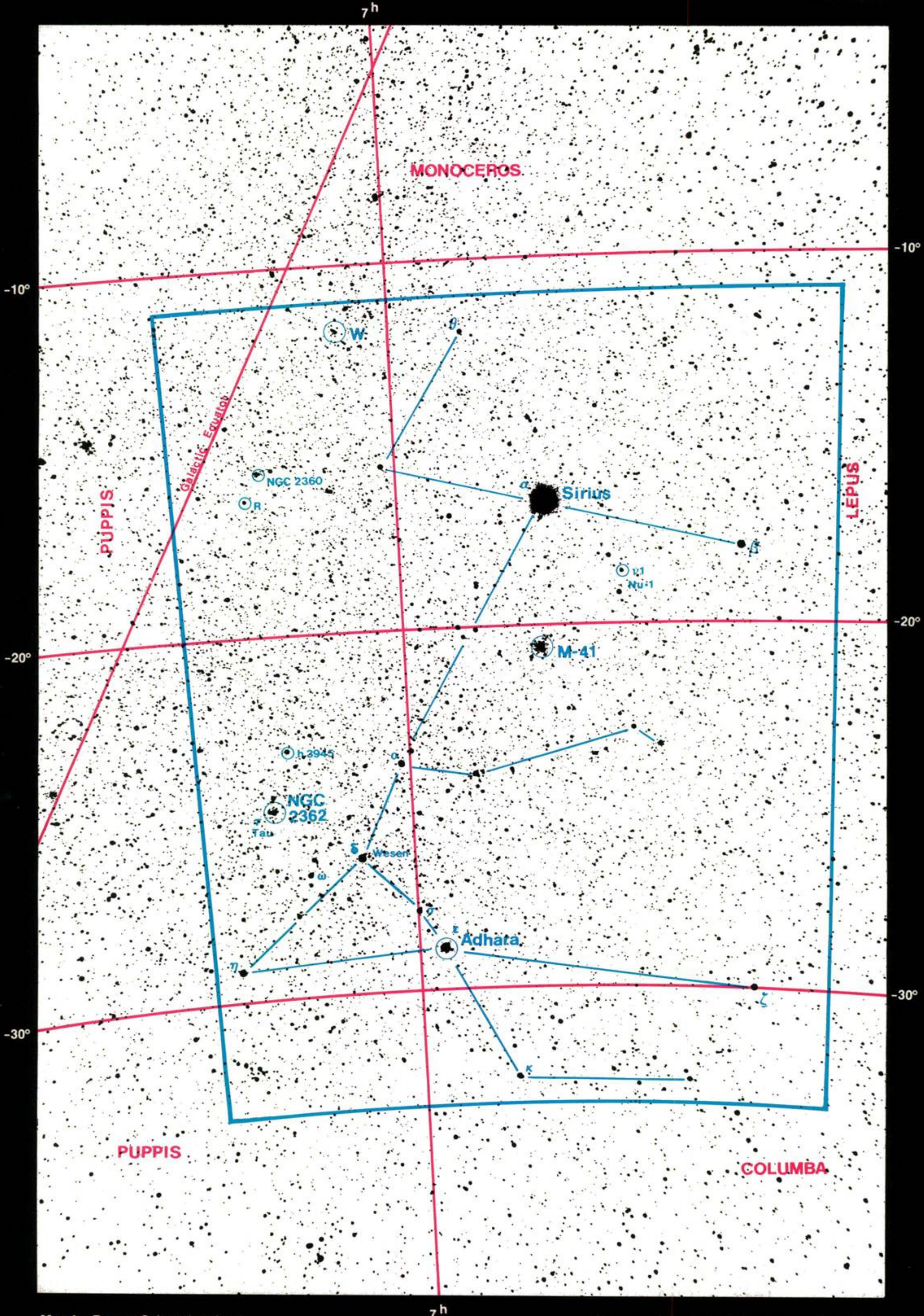
Webb aptly called this great star "the leader of the host of heaven: a glorious object", and pointed out that it has been glimpsed with the unaided eye in broad daylight and seen to cast shadows by night! He also made the following remarkable suggestion: "Its color has probably changed. Seneca called it redder than Mars; Ptolemy classed it with the ruddy Antares . . . I now see it of an intense white, with a sapphire tinge, and an occasional, probably atmospheric, flash of red."

In seeming support of these strange observations from antiquity, certain recent studies of stellar evolution indicate that Sirius' well-known white dwarf companion (Sirius B, described below) could have been in the red giant stage as recently as 2,000 years ago! Robert Burnham Jr. of Lowell Observatory does not rule out this facinating possibility, but thinks it more likely that the color sensitivity of the human eye has changed over the centuries. He notes that Ptolemy also classed Arcturus and Pollus among the "fiery red" stars and that Capella was described as red by ancient writers. If only stargazers had a time machine to travel into the past (and future)! How different might the night sky look?

Sirius is also one of the most intensely studied binary systems in the heavens. Its famed but elusive white dwarf attendant shines near magnitude 8.7 and currently lies 10.5 seconds of arc distant near position angle 50

Epoch 1950 coordinates

CANIS MAJOR


7h
MONOCEROS
-10°
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Sirius
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Adhara
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-30°
κ
PUPPIS
COLUMBA
7h

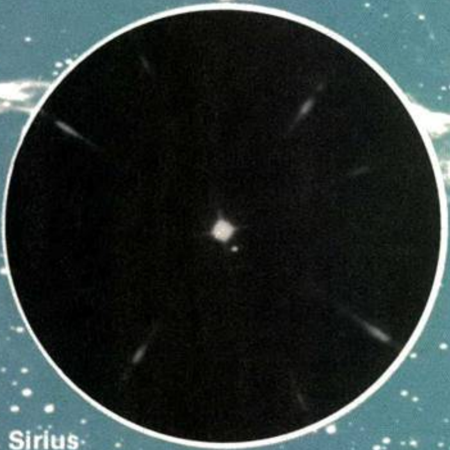
Map by Dewey Schwartzenburg

Photograph by Robert Provin and Brad Wallis degrees (northeast of the primary). This pygmy sun is the best known example of a "degenerate" star — one on its way to the stellar graveyard and ultimate extinction. Referring to its small size and remarkably high density, Barns stated that Sirius B "presents the supreme celestial paradox". This was a half century ago, and we must wonder what he would have to say of quasars, neutron stars and black holes were he with us today?

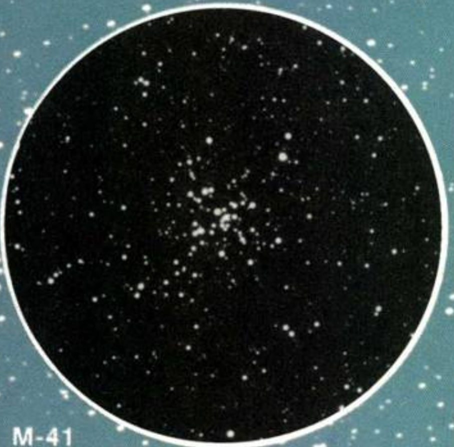
With an orbital period of just 50 years, the companion to Sirius has made more than two complete circuits of its primary since its visual discovery by Alvin Clark in January 1862, while testing an 18 inch refractor he had just made. The pair was last at its widest separation (just over 11 seconds) in 1972, and is now closing to another minimum of under three seconds in 1993.

Sirius B has been glimpsed in telescopes as small as a six inch refractor, and is an easy object in a 12 inch instrument when seeing conditions (image steadiness) are good. At present, a first-class eight inch scope (of all three basic forms — refractor, reflector or catadioptric) at about 200 power will reveal it on a steady night.

The vast difference in apparent brightness of Sirius A and B (a factor of 10,000 to 1!), combined with the relatively low altitude of this pair for northern observers and the often-poor seeing of winter, make this one of the most challenging objects in the sky for telescopists. The great double star observer S.W. Burnham once said of this duo: "An object glass of six inches one night will show the companion to Sirius perfectly: on the next night, just as good in every respect, so far as one can tell with the unaided eye, the largest telescope in the world will show no more trace of the small star than if it had been blotted out of existence."



Sirius



M-41

Sirius and its companion, a white dwarf star known as Sirius B, are shown in an unusual shot. Sirius B, while relatively easy to spot visually in a good telescope, is quite difficult to photograph because of the glare of the primary star, the brightest in the sky. The streaks are caused by secondary support in the optical system, and help to deflect light away from the central image where the dim white dwarf lies close by. Photograph courtesy of McDonald Observatory. The second shot shows M-41 as it would appear in a moderate sized telescope. This large cluster occupies an area as large as the full moon, so a low power eyepiece is essential for a good view. Photograph courtesy of Celestron International.

Selected Objects — Canis Major Region

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.
Nu (ν) -1	★2	5.8,7.9	18″	$06^{h}34^{m}$	-18°37′
*Sirius	★2	-1.4,8.7	10″	$06^{h}43^{m}$	-16°39′
*M-41	○	5.0	30′	$06^{h}45^{m}$	-20°42′
*Adhara (ε)	★2	1.5,7.5	8″	$06^{h}57^{m}$	-28°54′
*W	∩★	6.9–7.5	--	$07^{h}06^{m}$	-11°51′
h 3945	★2	4.8,6.8	27″	$07^{h}14^{m}$	-23°14′
NGC-2360	○	9.5	12′	$07^{h}15^{m}$	-15°33′
R	Ӿ★	5.9-6.6	1.14^{d}	$07^{h}17^{m}$	-16°18′
*NGC-2362	○	10	6′	$07^{h}17^{m}$	-24°52′

*Detailed in Close-Up

★2 = Double Star
○ = Open Cluster
∩★ = Irregular Variable
Ӿ★ = Eclipsing Variable

Even if your telescope doesn't reveal its elusive attendant, Sirius itself is a wondrous sight of light and color in even the smallest instruments on dark (moonless) transparent winter nights. As Olcott observed: "The sight of brilliant Sirius in a telescope is entrancing, particularly when viewed as it is rising or setting. Bright rays of every hue dart from its flaming hearts." And as Tennyson expressed it:

"The fiery Sirius alters hue,
And bickers into red and emerald."

The mere aspect of this great star in some of the large telescopes of the past was enough to convince their users that the stars are indeed other suns. With his homemade metal mirrored 48 inch reflector, William Herschel penned the following dramatic observation: "The appearace of Sirius announced itself . . . and came on by degrees, increasing in brightness, till this brilliant star at last entered the field of view of the telescope, with all the splendor of the rising sun, and forced me to take the eye from that beautiful sight."

Another Englishman was William Lassell who, like Sir William, used a 48 inch homemade reflector. Lassell wrote: "Sirius is an object I would challenge anyone to see as I see it, for the first time, without an involuntary exclamation of wonder! With 260 magnification, it is an incandescent diamond, which I cannot describe . . . . The pencil of light transmitted through the eyepiece from this star cast a brilliant spot on the wall of the observatory sufficient forcibly to attract my notice, without being at all prepared for it . . . ." Upon reading accounts like these, we can only wonder at the appearance of Sirius in the large reflectors of today's major observatories!

A modern 10 or 12 inch reflector will confirm the vivid impressions of Herschel and Lassel, despite the great difference in aperture. The eye should be well dark adapted, and Sirius placed outside the edge of the eyepiece field and allowed to drift slowly into view (from Earth's rotation) for optimum effect. And for a really startling experience, observe the star just after it has risen with the eyepiece racked slightly in or out of focus. You will behold an amazing multitinted flashing gem — a kaleidoscope of heavenly color! As Pickering pointed out long ago in the preface to his roster of the sky's finest showpieces, "For the casual visitor who merely wishes to see something brilliant and surprising, few objects excite more admiration than a first magnitude star thrown slightly out of focus."

Adhara

Greatly overshadowed by the glory of Sirius is another member of the exclusive stellar "first magnitude club" in Canis Major. This is the star Epsilon (ε) — better known as Adhara — located some 12 degrees southeast of Sirius itself. At magnitude +1.5, it ranks as the 22nd brightest star in the sky.

Like its nearby superstar, Adhara is a hot blue-white sun (of spectral class B) and an unequal double star offering a pleasing magnitude contrast. Its 7.5 magnitude companion is eight seconds distant near position angle 160 degrees (nearly due south of the primary), and it is easily split in a four inch scope at 100 power or more on a good night. A kind of copy of the Sirius pair, Adhara is much easier to resolve and makes a good "warm-up" for viewing the former. Despite the similarities, however, there is one striking difference between these two systems: At a distance of 680 light-years, Adhara is nearly 80 times as remote as Sirius!

W Canis Majoris

In stunning contrast to the blue-white radiance of our first two offerings, our next target displays a lovely deep red hue that will seem to warm you from across the light-years on frigid winter nights. This is W Canis Majoris, an irregular variable star of spectral type N, whose light cycles from 6.9 to 7.5 magnitudes in no certain period.

Always within reach of binoculars and finders, W is easily picked up by sweeping with a low power eyepiece on the telescope, 3.5 degrees due east of the fourth magnitude star Theta (θ) Canis Majoris. Especially attractive in six inch and larger reflectors, this restless crimson sun has been variously described as a glowing cosmic ember, a lofty celestial ruby, a colossal pulsating heart and even an interstellar traffic light! Why not have a look the next clear night and decide for yourself which seems most appropriate — or perhaps you will come up with your own terrestrial analogy?

M-41

One of the finest of this region's many open star clusters for small telescopes are the massed jewels of M-41. Just visible to the unaided eye on a dark transparent night away from city lights, it is easily spotted in a finder or binoculars four degrees nearly due south of Sirius (both objects fitting nicely within their typical fields of view).

A superb sight for rich field telescopes, this scattered grouping contains at least 50 member stars spread over an area some 30 minutes in extent. Classified as intermediate-rich as open clusters go, M-41's integrated (combined) light is equal to that of a fifth magnitude star. A recent determination of its distance from us places it at 2,400 light-years, nearly twice as far as earlier estimates.

Webb described this clan as: "Superb group, visible to naked eye . . . four degrees beneath Alpha. Larger stars in curves, with a ruddy star (Espin variable?) near center, 5.5 inch (refractor). John Herschel says the latter frequently occurs in clusters." Bernhard, Bennett and Rice said of M-41 in part: "A fine group . . . the stars dividing into groups and curves with a reddish star near middle. Called superior to the Perseus cluster." This last remark can be traced to Pickering's list, where he included M-41 and stated that neither member of the Double Cluster taken separately is the equal of M-41 or M-35 (in Gemini). Do you agree with this assessment?

Burnham considered M-41 "a beautiful object"; Brown noted that the stars here are "bunched in groups", and Muirden observed: "The brighter stars, some of which are orange, are arranged in distincitive curves. A splendid low power sight." Holyoke's account reads: "Still another splendid galactic star custer comparable to those in Gemini and Auriga. It can be seen with the naked eye on a good night, and is a beautiful sight in a very small telescope at 25 power or more. A red star near the center is a striking feature."

The **New General Catalog** mistakenly labels M-41 as M-14 and gives the following summary: "Cluster, very large, bright, little compressed, stars from the eighth magnitude downward." Barns, in his 10 inch reflector, found it "Truly imposing, even with low power. Ruby central star. Probably faintest object recorded in classical antiquity — Aristotle, 320 B.C." And for owners of small instruments, there's Olcott's impression: "It is a superb group in a three inch glass, and the red star near center shows very clearly." The red star mentioned in most of the foregoing descriptions is also reported as orange by some observers. How do you see it?

M-41 is perhaps at its sparkling best in four to eight inch scopes at 30 to 60 power. Here, as with other clusters situated at low sky declinations, those infrequent nights having both good seeing and transparency should be sought for a really optimum view. However, there is one effect caused by observing such objects at low altitude in poor seeing that shouldn't be overlooked — the striking transformation of the cluster by atmospheric turbulence into a glittering swarm of cosmic fireflies in the night!

NGC-2362

We conclude our sampling of this month's region with another open cluser — this one looking like some exquisite piece of cosmic jewelry due to the presence of a bright central sun in its midst. This is NGC-2362, surrounding the fourth magnitude star Tau (τ) Canis Majoris, some 10 degrees southeast of Sirius and three degrees northeast of Delta (δ). As Sirius overshadows Adhara, so M-41 seems to take attention away from this little group; it is seldom observed by astronomy enthusiasts.

Another of the many finds of William Herschel, this object is also designated HVII-17 (or H17^{7} in some atlases) in his great catalog of nebulae and clusters. Softly glowing at 10th magnitude and measuring only six minutes in size, it is considered loose and poor despite 40 or so member stars. It is the presence of Tau itself that transforms this obscure clan into something of a minor showpiece within its class.

The classic observers had little to say about NGC-2362, apparently due to its southerly declination of -25 degrees. One of the very few modern accounts available is that by Robert Burnham: "An unusually attractive and interesting cluster of stars surrounding the fourth magnitude star Tau or 30 Canis Majoris .... In very small telescopes the object may at first present the appearance of a nebulosity about the star, but any good two inch telescope should resolve it easily into a rich little cluster of some 40 stars."

Tau apears to be an actual physical member of NGC-2362, rather than a projected foreground object, and is intrinsically one of the brightest stars in the sky. A spectroscopic binary having an orbital period of 155 days, the primary is a hot O type supergiant, some 50,000 times as luminous as the sun. Viewed from its distance of nearly 5,000 light-years, our home star would appear no brighter than 16th magnitude.

In striking contrast with Tau itself, the individual cluster members are rather faint, and at least an eight inch aperture is needed for a really good view on a typical night near city lights. In such an instruments, the Tau-NGC-2362 grouping looks like some celestial diamond surrounded by a rich stellar setting — a sight never to be forgotten!

Whether it be the dazzling splendor of Sirius or the sparkling glow of NGC-2362, a winter's evening spent viewing the wonders of Canis Major may well find you in accord with what Ezra Pound wrote from the death cells at Pisa, while looking at the stars: "Out of all this beauty something must come."

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